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An Abductive Framework for Interactive Data Visualisation Development from Organisational Semiotics Perspective

By

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

The development of IDV (Interactive Data Visualisation) takes into account users' inputs, visualisation and analysis, in order to comprehend dataset. Insufficient research focuses on the methodology of developing IDV, with a particular emphasis upon acquiring and managing user demands as well as with different interpretation purposes and in various business contexts.

It is vital to construct a framework for facilitating the IDV development. This can help visualisation designers to understand how users make sense of datasets and to deploy suitable interactive mechanisms for the corresponding demands. This research delivers an Abductive **F**ramework for **In**teractive **D**ata **Vi**sualisation **D**evelopment (FINVID) based on exploration and illustration in two case studies. It mainly lays the building blocks of organisational semiotics, the doctrine of signs in the context of business and organisations. IDV development can be interpreted as a socio-technical design, which needs to establish a holistic view of users' requirements, including both technical and social aspects. Abduction is also embedded in FINVID to iteratively acquire and incorporate students' updating demands during the IDV process. IDV development is assumed to maintain an equilibrium between the following three aspects: process and artefact, data and interpretation and subjectivity and objectivity. To be specific, firstly, FINVID portrays IDV development as a norm-centric process, where users' requirements can be articulated in norm specification to be documented and communicated among different stages of IDV development. Secondly, FINVID adapts an abductive reasoning process in IDV development, where users are empowered to continuously address their new request while exploring and analysing dataset via IDV. Finally, FINVID enables IDV to facilitate users' knowledge exploration. It demonstrates six significant steps of IDV development with abductive nature. It specifies sub-activities and techniques for each step, which involve different stakeholders. This method is used to acquire and refine users' knowledge.

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Contents

List of Equations

List of Figures

List of Tables

Related Publications

Li, Q. and Liu, K. (2016) ‘Interactive Data Visualisation: Facilitate the Accountability Disclosure Through the Lens of Organisational Semiotics’, in Baranauskas, M. C. C. et al. (eds) *Socially Aware Organisations and Technologies. Impact and Challenges*. Cham: Springer International Publishing, pp. 133–142.

Li, Q. and Liu, K. (2018) ‘An Abductive Process of Developing Interactive Data Visualization: A Case Study of Market Attractiveness Analysis’, in Liu, K. et al. (eds) *Digitalisation, Innovation, and Transformation*. Cham: Springer International Publishing, pp. 289–298.

1. Introduction

This chapter sets out the research scope and direction of developing interactive data visualisation. It delivers an overview of the research background and motivations, pinpoints the research questions based on theoretical and empirical views, and outlines the research aim and objectives which structure the whole research. The end of this chapter briefly describes the potential contributions of this research as well as the structure of this thesis.

1.1 Research Background and Motivations

Data visualisation is a method for assisting people to make sense of various datasets with a visual image (Latham, 1995). Ware (2004) further points out that a picture is worth more than a thousand words, which echoes the examples back in the 1500s, when maps and diagrams were used to record planetary movements over time. A few milestone examples, such as John Snow's map of the London Cholera epidemic (1854) and Florence Nightingale's Rose Chart revealing the leading causes of soldiers' mortality in World War I (WW1), demonstrated how data visualisation method helped decision-makers quickly capture the main features of datasets and assists their decision-making (Friendly, 2006). With the development of in-memory computing and cloud applications, various interactive functions have been gradually added into the design of data visualisation, which is called Interactive Data Visualisation, which enables the visual presentation to be responsive to the users' input and to be adaptive in different context and user's purposes (Barbulescu, Stoica and Stoica, 2016). Different from the traditional static data visualisation, interactive data visualisation can be 'dynamic' to empower users to address their ad-hoc information demand and to explore the dataset based on their mental model. In short, interactive data visualisation has been generally recognised as a method to help people, including both experts and novices, to make senses of various datasets, by visually perceiving and interactively analysing the data trends and patterns presented by visual means (Lee *et al.*, 2016).

Although the contributions of data visualisation towards enhancing human's perception and cognition of datasets have been generally recognised by both academia and practitioners, the definition of data visualisation remains unclear and research focuses also vary among prior researches. This claim is also supported by Purchase et al. (2008), Smith *et al.* (2011) and Baškarada and Koronios (2013), which tries to integrate different theories related to data visualisation. Referring the surveys conducted by Wang et al. (2016) and Featherstone (2017), the research focus is on human perception, such as pre-attentive attributes, colour cue and algorithms of visualisation-making or selecting. Also, the researchers tend to focus on the sense-making process, where the visualisation pipeline, users' demands and purposes, and context are more often discussed to guide the design of interactivity (Segel and Heer, 2010).

When it comes to industrial practice, data visualisation supplies an essential function of exploring patterns and trends hidden in the datasets with the characteristics of complexity and high volume, which enable it to be incorporated into various contexts and to serve different purposes. It can be used to present the data analytic results in the fields of natural and social science researches in order to help readers quickly perceive the mainstream changes of data during a given time. In addition, data visualisation can be widely utilised for business purposes, such as identifying the changing patterns of sales data, analysing the correlation among the income generated from different products, and comparing different market growth based on a series of performance indicators. Compared with scientific data visualisation where the results will be communicated among peers within the same or related research field or with the similar knowledge background, the data visualisation for business purposes will be applied as a bridge to connect data scientists and technique-novices and integrate data, information, and knowledge from various sources to facilitate the decision-making. Therefore, the scope of this research concentrates on the issue of developing interactive data visualisation in the context of business.

Driven by the idea of Big Data where great value can be discovered from datasets, business companies and even non-for-profit organisations (incl. charities) have gradually shifted to the paradigm of data-driven decision-making. Incorporating prior knowledge and experience into data analysis, companies and charities all expect to enhance their capacity to make sense of data and obtain guidance to improve their profitability or efficiency. Interactive data visualisation, as an important component of data intelligence tool, enable users to explore, make sense of and communicate with visual aid and interactive functions. The existing visualisation tools, such as Tableau and QlikView, are able to offer a virtual data visualisation workspace where various diagrams and charts can be made via "click-and-drag". However, the ultimate goal is to present the right information, on the right occasion, with a right process and in a right context, instead of simply producing a picture (Liu and Tan, 2015). The existing visualisation tool, to some extent, underestimates the complexity of making sense of data, including not incorporating the consulting process to capture users' prior knowledge, information demands, intentions and the context for decision-making (Few, 2007). Therefore, the real challenge for both theoretical development and practical advancement remains on how to understand the process of interactive data visualisation and justify the reason why the interactive function should be placed on a certain occasion. Other than regarding data visualisation solely as a visual representation of datasets and focusing on the authentic aspect, the research focus gradually shifted to understanding data visualisation as a process of data exploration and interrogation.

Therefore, the motivation of this research is to construct a framework for developing interactive data visualisation in the business context, where the framework can help visualisation designers better understand the process that users make sense of dataset and to deploy suitable interactive mechanisms for the according demands. To some extent, it can be regarded as a solution to the dilemma where the

data visualisation process can help identify stages of visualisation design but cannot effectively justify why an interaction should be placed in a certain place. Without understanding the reasoning process and having an effective approach to connect the interactive functions and user' demands, the final visual representation might not be able to serve for readers' purposes and the contributions of interactive data visualisation would be undermined. Inspired by the research conducted by Liu and Tan (2015), this research also is intended to configure a theoretical proposition for developing interactive data visualisation, which covers the basic concepts and the logic reasoning approach behind visualisation process.

1.2 Research Questions

This sub-chapter discuss the necessities and potential issues of developing a framework for guiding the development of interactive data visualisation from theoretical and practical perspectives, followed by the illustration of the research questions.

1.2.1 Theoretical Aspect

The theoretical foundation of data visualisation is unsubstantial due to the inconsistent theoretical propositions and absence of systematic methods (Friendly, 2006; Few, 2007; Hauser, Rheingans and Scheuermann, 2018). Referring to the Liu and Tan (2015), data visualisation can be perceived as a process of making sense of dataset with the visual representatives as well as transferring knowledge between authors and readers. The perspectives of data visualisation as a process also comes from a few authors (Ware, 2012; Nguyen et al., 2016; Wang et al., 2016), where the data visualisation should be aware of users' demands, intentions and context. There are several portrayals of the data visualisation process based on the its application with various focuses and propositions, which confuses the following researches to select the best suit process to a special problem domain. Therefore, it is necessary to establish a systematic theoretical proposition for developing data visualisation.

Interactivity plays an increasingly significant role in data visualisation, which enables the visual representatives to adapt to users' scenarios. The prior research also points out the contributions of interactive functions in terms of facilitating the communication between authors and readers, enabling the collaborative interpretation among multiple stakeholders, enhancing the accessibility and adjustability of visual representative, and supporting knowledge acquisition. The interaction has been embedded into the various models of data visualisation and data analytics, such as cognitive loop and user feedback loop. However, the existing research still cannot offer a crystallised and validated framework which underpins the process, mechanisms and consulting methods for deploying the interactive functions on top of data visualisation.

To construct the framework, it is necessary to decode the process where readers interpret and interact with visual representatives. Zeng and Cheng (1991) claims that the logical reasoning process constitutes

the vein of a design process. Existing research presents the discussion of incorporating various logical reasoning processes as the backbone of data visualisation development as well as a conceptual guideline for interpretation. However, the literature does not associate it with specific methods of visualisation development on the application level. Thus, the logical reasoning process embedded into interactive data visualisation development needs to be systematically reviewed and to be interconnected with the methods in the application levels.

Based on the discussion above, there are two research questions raised here, which are as follows:

- How to articulate a set of theoretical propositions supporting the methodology of developing an interactive data visualisation?
- How to portray a logical process of developing an interactive data visualisation, which can cover the development, validation and refinement of IDV artifacts?

1.2.2 Practical Aspect

When it comes to the practical perspective, this PhD research mainly focuses on the application of interactive data visualisation in the scenarios of charity reporting and marketing intelligence for global market analysis.

Charity refers to the organisations which raise money from the public to help disadvantaged and helpless people (Hyndman, 1990). Different from other public and private organisations, it should focus on serving the public interest instead of profit; its funds mainly come from individual or organisational donations and business subsidiaries; exempted corporate tax can be regarded as an 'indirect fundraising' from the social public; and its operation and performance should be accountable to the general public, including its financial efficiency and activity effectiveness. According to (Charity Commission (2019), there are 168,410 charities registered in England and Wales, which possessed £77.07 billion of income in 2018. Within the total income, around 30% of income comes from voluntary donation of individuals and organisations, and 50% of income comes from charitable activities e.g. transactions in the charity shops. Thus, this reveals the fact that the operations of UK charities rely on the funds from the social public and should be responsible for using the funds efficiently to serve the interests of the public. At the same time, all people who make up the social public should be granted the rights to supervise the operations of charities, including accessing the operational information, understanding the input (income) and outcome (performance and outcome) and then deciding if they continue to support (vote with actions).

Based on the Charity Act and SORP (Statement of Recommended Practice), it is compulsory for all registered charities in the UK to publish an annual report on their website to ensure accountability of its operations and performance. The disclosure mechanism is specifically designed to enable the social public to evaluate the contributions of charities and decide their economic support (donation) and non-

economic support (voluntary participation). However, most charities follow the traditional reporting practices, and publish the information on the format of narrative report and financial report with static data visualisation via their official websites. In other words, its content fits predefined layout, details and formats, which hardly fulfils the diverse information demands from a wide range of readers. Referring to Stewart (1984), accountability does not only indicate offering an account to stakeholders but also being accountable – enabling stakeholders to supervise the operation and performance. Therefore, it is necessary to incorporate interactive data visualisation into charity reporting practices.

Marketing intelligence (MI) emerges as a useful tool helping managers to gain a deep insight of market needs and market development trends, including identify market segments and partnership opportunities (Trim and Lee, 2008). It can also be understood as a system associated with a set of procedure used by marketing managers to retrieve the information needed for forming a marketing strategy (FAO, 2017). Kartika (2017) further emphasises the MI function that MI should be able to answer the questions of management via bridging between information systems and management consideration. However, enabling the MI tool to deliver the suitable information which fits the right time, right person and right context remains a challenge. Especially in an organisational context, this requires a framework to holistically incorporate the process of understanding users' needs in interaction, navigation and data preparation.

Gartner (2017), after reviewing more than 30 tools offered the mainstream vendors on the market, finds that the development of cloud techniques, Big Data analytics and AI reveals an increasing amount of opportunities to facilitate an accurate understanding of the dataset. There are still obstacles for the further move of interactive visual exploration, which enables users to analyse and manipulate the data directly interacting with the visual representations as well as to deliver insight in a quick pattern, improve memory efficiency and leads desired actions in the business context. Other than the advanced algorithms for augmented analytics and interactive functions of data visualisation, it requires methods underneath to enable the data storytelling and user enablement, such as capturing users' prior understanding (what proposition and hypothesis), requirements (what information), purposes (what is it for) and contextual pressure or simulation. Therefore, there is a need to develop a framework leading the development of interactive data visualisation in the scenario of marketing intelligence.

Inspired by NAM (Norm Analysis Method) from Organisational Semiotics, a norm can be used as an important carrier to capture the readers' demands, with specific focuses on prior understanding, information demands, analytic purposes and contextual pressure/drivers. Norm are generated through practical experiences of human agents in an organisational context, which contains the underlying rationales for interpreting and act upon the information (Stamper *et al.*, 2000) . Understanding users' prior hypothesis and interpretation rationales is essential for designing the visualisation layout and interactive functions, which enables users to apply their rationales into visual analytics and provoke

new propositions based on revealed information (Chi and Card, 1999; Ahn, 2010; Kodagoda *et al.*, 2013). However, the application of norms in visualisation development remains at a conceptual level, without a solid association with specific methods and practices. Thus, it is significant to embed the concept of norm and norm-based analysis into the process of developing interactive data visualisation.

Based on the discussion of practical issues above, the research questions will be listed as follows:

- What are the key measures applied in a process of interactive data visualisation in order to facilitate sense-making in the scenario of market intelligence and charity reporting?
- What are the impacts of incorporating the norms-embedded process towards helping select and justify the interactive functions in process of IDV development?

1.3 Research Aim and Objectives

This research aims to construct a framework for developing interactive data visualisation. The framework aims to fulfil the gap in the theoretical development of interactive data visualisation, and a logical reasoning process will be embedded into the framework, which helps to better understand human's sense-making of datasets. In addition, norm-based process will be introduced to the construction of framework, for the purposes of incorporating social and technical factors, e.g. humans' prior understanding, purposes and context, and articulating them to the specific interactive function designs. Finally, the framework can be used as guideline for the employment of diverse visualisation techniques to serve the different users' demand in different domains. The research can be further divided into five research objectives, echoing the four research questions.

- To build a basic concept and by reviewing the relevant literature on the development of data visualisation, including the definition of data visualisation, basic principles of designing data visualisation, foundational process of data visualisation and logical reasoning behind the design process.
- To specify the logic reasoning approach of data visualisation process, for the purposes of helping designers understand the process where users make sense of datasets and offer guidance for the visualisation design.
- To incorporate a norm-based approach into the construction of data visualisation framework. Norm-based process will be utilised as an approach to elicit users' requirements, purposes and context, which enables capturing both technical and social aspects of users' requirements. The social aspects associate the purposes and motivations of analysing data; the technical aspects relate to how data should be presented through technical components, such as charts and interactive functions.
- To apply the framework of developing interactive data visualisation into the case studies of market selection and charity report. The logic reasoning approach and norm-based approach

will be incorporated into the case studies in order to guide the design of interactive data visualisation.

- To validate the interactive data visualisation framework via case studies. The observation of users' interactions with data visualisation and feedbacks from users will further promote the discussion in terms of the contributions and limitation of this research.

1.4 Expected Research Contributions

The research intends to construct a framework of developing interactive data visualisation, for the purposes of addressing the issue of sense-making. Therefore, the findings of this research can be beneficial to both research community and practitioners of interactive data visualisation in terms of theory development and good practice promotion, respectively. To be specific, the contribution of this research can be further described in theoretical, methodological and practical aspects.

In terms of theoretical contributions, this research configures a theoretical proposition for developing interactive data visualisation in the context of business, where the statement of 'data visualisation as a process' has been further developed by embedding a logic reasoning approach. Thus, it can help reduce the ambiguities in the prior frameworks and reveal the whole process where people make sense of dataset. It will eventually unlock contribution of interactive data visualisation towards helping human to mine the value from data.

In terms of methodological contributions, this research offers a method of developing interactive data visualisation, where abduction as a logical reasoning process is incorporated, in order to enable visualisation designers to understand readers' sense-making process. Each stage of the abductive process contains the utilisation of sign and interpretation, which can be supported by organisational semiotics which reveals the sign as a carrier to deliver information among different parties. In addition, inspired by the norm-based approach in organisational semiotics, each stage within the process will be supported by norms that profile users' demands, purposes and context. Norms will also help elicit both social and technical aspects of users' demands, and then this can be further used as guideline to justify the design and selection of interactive functions which enables users to explore the dataset.

In terms of practical contributions, the framework of interactive data visualisation produced by this research can further promote the real practice. As is illustrated in the case study, this framework can help visualisation producers better understand the sense-making process adapted by readers. Then, different interactive functions can be assigned to further facilitate readers to explore dataset and make sense of the information. Additionally, the utilisation of a norm-based approach can allow visualisation design to understand the users' requirement from various aspects, such as social and technical ones, which will support the visual presentation to be able to deliver the right information to a right people, a right context and to serve a right purpose. In particular, in the case studies, the framework of interactive

data visualisation will be applied to the scenarios of market selection, which helps users to quickly compare different markets based on their attractiveness indicators and find the most suitable market to launch their new products. It will also be applied to the scenarios of charity reporting practices, which empower different readers to evaluate the performance of charities based on their criteria.

1.5 Thesis Outline

The structure of this thesis follows the process of abductive reasoning, since it adapts abductive reasoning process as a fundamental approach to guide the development of interactive data visualisation. The abduction process enables a researcher to interpret a puzzlement with a reference to their prior knowledge and to generate a new proposition and hypothesis based on observation, which will be further elaborated in the following chapters. This thesis consists of eight chapters (Figure 1-1).

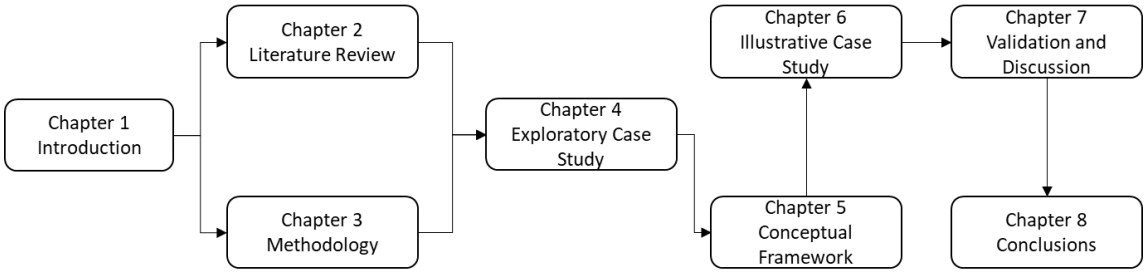


Figure 1-1 Thesis structure

Chapter two reviews the concepts, definitions and mainstream models of data visualisation, with a specific focus on the role of interactivity in data visualisation and comparison of different models of data visualisation and data analytics in the business context. Afterwards, the chapter further discusses the different portrayals of interactive data visualisation as a process of sense-making, which links to the discussion of organisational semiotics, which lays a basic proposition for developing interactive data visualisation. Semiotics, as a doctrine of sign, illustrates the process of information delivery among different parties. Organisational semiotics then further brings the theory of semiotics to the context of business organisations with a series of methods to understand the facilitator and barriers of communication, which serves a theoretical foundation of developing interactive data visualisation. The abductive reasoning process and knowledge management are discussed as subsets of OS theories. Finally, this chapter discusses the concepts and models of marketing intelligence and theories of charity reporting for illustrating the necessities and contributions of developing interactive data visualisation in the scenarios of charity reporting practice and marketing intelligence development.

Chapter three discusses the dominant research paradigm, approaches, methods and techniques in the information system research, especially understanding socio-technical systems. This chapter will also discuss the importance of adaption abduction process as main guideline for research development, with a comparison of deduction and induction. Organisational semiotics is illustrated as the dominant

research methodology, and along the line of design science as research paradigm and case study as research technique. At the end of this chapter, the research design and development are illustrated a detailed level, incorporating the discussion of adapted research paradigm and methodology.

Chapter four examines the initial theoretical propositions in the case study of UK charity reporting practices as a preliminary exploratory study. In this chapter, the design of exploratory study is informed by design science paradigm and case study techniques. The initial IDV development process and techniques will be preliminarily examined via developing a prototype of interactive data visualisation in the scenarios of charity reporting, including abductive reasoning process, norm specification and knowledge exploration. Finally, the preliminary feedback from readers is interpreted through the lens of organisational semiotics and obtained results are applied to further construct the framework of IDV development.

Chapter five portrays the development of Abductive **F**ramework for **In**teractive Data **Vi**sualisation **D**evelopment (FINVID). Abduction is applied to lead the process of developing interactive data visualisation. This chapter elaborates the six steps of developing data visualisation, consisting of 1) capturing and organising participants' prior knowledge for initial visualisation construction; 2) establishing the initial propositions based on the initial observation; 3) matching and updating information to the prior knowledge; 4) identifying the gaps; 5) addressing further questions; 6) refining/generating new knowledge for guiding the following actions. This chapter provides a conceptual framework which further derives the holistic methodology in the case studies in the following chapters.

Chapter six utilises the FINVID in the case study of marketing intelligence for global market selection. In this chapter, the refined conceptual framework and real-life observation (incl. user feedback) contributes to the finalisation of the abductive framework of IDV. The IDV development follows the six steps of abductive reasoning process. In each step, specific sub-activities and techniques are applied, including norm specification for requirements management, think-aloud sessions for acquiring users' feedback and new requests, consulting sessions for expert's inputs and knowledge exploration and six layers of IDV development: data, model, visual representation, interactive functions, navigation and storyline. The application of FINVID demonstrates the validity of adapting abductive reasoning process to scenarios of interactive data visualisation development.

Chapter seven mainly focuses on the validation of the FINVID based on readers' and experts' feedbacks. Semi-structured interview is utilised to collect feedbacks, which covers the four aspects of FINVID, including validity, generalisability, usefulness and innovativeness. In addition, the chapter discusses the implication and limitations of Abductive Framework of IDV.

Chapter eight draws conclusions from the PhD research work. It concludes the overall research activities for constructing, applying and validating FINVID, its contribution on theoretical, practical and methodological perspectives, its limitations and its inspiration for future work.

2. Literature Review

This chapter covers the critical review of relevant prior studies, for the purpose of laying a theoretical foundation for IDV development. It starts with overviewing the evolution of data visualisation with an emphasis of the key milestones and their impacts, followed by the discussion of visualisation systems, principles and components, which can help further understand the mechanism used for IDV development. Semiotics, the doctrine of sign, is also reviewed as a theoretical foundation in this research for decoding the process where information can be conveyed through visual representations. The discussion of abductive reasoning process can offer a new perspective to understand IDV development as a reasoning process as well as the interaction between readers and visualisation interface. Finally, three key assumptions are proposed based on discussion of prior literature, which can guide the construction of IDV development framework.

To be specific, this chapter consists of five sections. Sub-chapter 2.1 discusses the concepts of data visualisation including the development of data visualisation. Sub-chapter 2.2 discusses the visualisation systems, principles of visualisation development and components of data visualisation, which constitute an important guideline of visualisation development. Sub-chapter 2.3 reviews organisational semiotics as a fundamental theory for guiding the development of data visualisation methods, which includes the key concepts and theories of semosis, semiotic ladder, requirement engineering, and roles of norms and knowledge management. Abductive reasoning process as well as concepts of sensemaking in the context of visualisation are reviewed in sub-chapter 2.4, followed by three key theoretical propositions for guiding the IDV development. In sub-chapter 2.5, three assumptions are constructed based on the reviewed literature, which include the balances between 1) artefact and process; 2) interpretation and data; 3) subjectivity and objectivity.

2.1 Data Visualisation: Definition and Development

2.1.1 Data Visualisation

The definition of data visualisation varies in different pieces of research due to the diverse research focuses and application scenarios. Each definition carries a different focus towards the functions and contributions of data visualisation, including the view of software system, methods, process, communication approach and technique. Data visualisation can refer to the software system which involves visual display enabling users to interact with the view of dataset for the purpose of constructing a mental model (Spence, 2007). Data visualisation can also be defined as a method of enhancing the sense-making of data with the advantages of visual techniques, such as cognition amplifying and perception decluttering (Few, 2006; Quigley, 2013). It can be further defined as a process of interpreting data in a visual term or loading information into a visible form (Griethe and Schumann, 2006). Visualisation can be understood as a common approach of adjusting the visual representations for

addressing data patterns based on users' needs and tasks (Ben Shneiderman, 1996). Card, Mackinlay and Shneiderman (1999) pinpoints that visualisation refers the techniques of using computer-aided and interactive visual representation of data to enhance human cognition – devise an external aid via a dynamic, interactive and affordable medium to help with interpreting data. In this research, the definitions above can be integrated as a working definition that data visualisation is a process where various visual representation and interactive techniques are employed to enable understand the meaning of data, interpret the data with their purposes, and make sense of data for leading the following actions.

For the contributions of data visualisation, different research shares different perspectives. Tufte (2001) articulates that graphical display needs to provoke viewers to think behind the data itself, including central trends, coherence among datasets, comparison among different viewpoints, several levels of details as well as a board view based on a fine structure. He further points out that information workspace for visualisation should be orientated around visual token themselves but focus on tasks. Revealing insights should be the ultimate purpose of visualisation, including rapid information assimilation or monitor the change of data series. Spence (2001) portrays the visualisation as a process of forming a mental model of data, and then gaining an insight into the data, including identifying the patterns and features of visual display. This echoes Ware (2010) that visualisation is constructing a visual image with a reflection of understanding and interpreting datasets, and transferring the internal construct of mind model to an external artefact for supporting decision-making. In addition, Friedman (2012) states that visualisation offers the chance to transform data into diagrams and provides a deep interpretation of data. The patterns and trends contained in the dataset can be revealed by the visual functions.

Compared with the various ways that human perceive this world, such as touching and hearing, vision can be regarded as a dominant approach (Chen, 2017). The explanation behind is that vision can enable a wide bandwidth for extracting information in an effective pattern. To be specific, it can attribute to the pre-attentive pattern of visualisation and cognition system, which will be further discussed in the sub-chapter 2.3.1. The motives and importance of data visualisation are discussed as follows.

Firstly, data visualisation can be used to explore new data patterns and to further infer information and knowledge from the dataset via graphic means. Data visualisation, regarded as a tool, can help users to quickly capture the dominant trends and patterns hidden in the datasets, which cannot be easily identified in the numeric format (Luo, 2019). For example, based on the comparison of colour and shapes of visual representatives, users can perceive the changes across the datasets. In addition, data visualisation can further facilitate the data exploration based on the prominent data patterns (Vickers *et al.*, 2012). Users can interpret the revealed data patterns and generate new information with relevant purposes, and then further refine their knowledge which might further impact upon their following behaviours (Reda *et al.*, 2014). For example, a marketing manager can use visualisation to capture the

mainstream change of sales, then interpret as a growing or declining trend, and finally constitute a reference for his decision on a marketing strategy.

Secondly, data visualisation can facilitate the cognitive effect via visual representation. Other than enhancing the human perception, data visualisation can help with easing the cognitive load or attract cognitive focus (Anderson *et al.*, 2011). The term "decluttering" refers to how data visualisation can help users filter the irrelevant data patterns and reduce the workload of recognition and even confusion (Yeh and Wickens, 2001). Data visualisation can also contribute to navigate the focus of users to the most relevant data patterns based on the readers' input of purposes and contextual information. Although it echoes the statement that data visualisation should be purposeful and context-aware (Schoffelen *et al.*, 2015), it remains a challenge due to the lack of procedure and mechanism of eliciting, managing and address users' purposes and contextual information.

Thirdly, data visualisation can facilitate the sense-making of datasets due to the following four features – being informative, efficient, appealing and interactive – which further constitute the criteria as well as challenge the effectiveness of data visualisation (Few, 2017). Data visualisation is informative, since it can deliver or prompt the desired data patterns from the datasets to the target readers (Encarnacao, 2017). Data visualisation is efficient since it can quick reveal the dominant patters in the datasets via visual vehicles, such as colours, shapes and proximity (Van Wijk, 2005). Data visualisation is appealing, since the visualisation artefact should be generally accepted and visually perceived in the readers' social context (Strecker, 2012a). Data visualisation can be interactive, which enables users can adjust the setting of datasets, such as calculation and filtering, and examine the variance of results in different scenarios (Blanch, 2014).

2.1.2 Social aspects of IDV development

Interactive data visualisation (IDV) can be defined as the computer-aid data visual representation which enables users to interact with data via selecting the interested data object as well as adjust the presentation for helping with sensemaking (Dilla, Janvrin and Raschke, 2010). Interaction is one key factor that helps differentiate IDV from the traditional static visualisation. The interaction function enables readers to customise the contents and layouts of visualisation for aligning with their information needs and reasoning process and interpret data from different perspectives (Li and Liu, 2016). Tang *et al.*, (2014) investigates on the impact of interactive function in visualisation with a case scenario of financial report analysis. The result reveals a high level of interaction embedded in the visualisation generate a positive impact on the accuracy of decision-making since it can supply the information based on demands and enhance the alignment between users' interpretation and data objects. The detailed discussion of interactive features in IDV can be found in the sub-chapter 2.3.4.

The key challenge of IDV development lays on the understanding and incorporation of the social aspect of IDV. Other than developing technologies for visualising data, aligning technology with users'

requirements, specifically with their information demands, interpretation purposes and sensemaking context needs to be highlighted as well (Keim, Andrienko, J. Fekete, *et al.*, 2008; Fagerholm and Andersson, 2018). Therefore, IDV development needs to be view as a socio-technical process. Inspired by the concept of social informatics from Kling (1999, cited in Kling, 2007), utilisation and consequences of information technology involve the interaction between users and their surrounding context, including their institutional and cultural environment. Nakata (2008) further addresses a framework of understanding and analysing the impacts of context from cognitive view, computer-supported cooperative work and human-computer interaction. He also recognises that participation (cooperativity) of users in the process of technology development can help incorporate the consideration of social factors into the technology development and uses for facilitating information sharing/retrieval performance. Zainol and Nakata (2010) classify the context into three categories. Intrinsic context refers to the users' attributes, like their profile, preferences and emotional status; interface context refers to the activities where users interact with the environment, like reading information and asking questions; extrinsic context refers to the environmental context where users make sense of and make a decision based on the perceived information. The three layers of context are adapted in this research for specifying the intrinsic context of users by making user persona at the initial stage; for analysing interface context by scheduling think-aloud session where users interaction and feedback can be captured; for evaluating the extrinsic environment by implementing consulting workshop where the experts and other relevant stakeholders can work together to identify the contextual pressure and make sense of data.

Liu, Nakata and Harty, (2010) further develop Societal-Technical System Theories (STS) by specifying the technical (physical) and social space. Although the concepts were demonstrated in the context of civil engineering, they can be generally applied to the scenarios of alignment between technology capacity and social demands. The technical space refers to the artefacts, which provides the technical functions. In the context of visualisation, it can be the visualisation software, data integration/process servers, and algorithms for developing and optimising visual representations. The social space refers to the cultural setting, relationships and interactions among different stakeholders which can be explicated and facilitated above the technical space. In the context of visualisation, it can refer to users' sensemaking context like the influence of colleagues, executives, and even shareholders towards their interpretation purpose and information demands. Stemmed by the theory of organisational semiotics, they develop a set of methods for examining the alignment between technical and social space, which further developed by (Liu *et al.*, 2011) in the business scenario, referred as "business-technology alignment". It is consistent with the opinions from Beynon-Davies (2009) that OS theory supplement STS with an implementable method of analysing the interoperation between social and technical aspects of information systems (IS). To be specific, Beynon-Davies (2010) points out the sign-based information can be utilised to identify intentions, making decisions and provoke actions. Tan, Abdaless

and Liu (2018) further highlight the application of norms in OS theory can help with articulating requirements and rules of social interaction which can guide the development of technical artefacts. Therefore, in this research, the social aspect of visualisation is placed on the spotlight for achieving the alignment between users' dynamic demands and development of visualisation artefacts (sign in OS theory). Norms, as a tool as well as a method, are utilised to acquire, specify and communicate users' requirement with consideration of information needs, intention of interpretation and sensemaking context. The relevant discussion of OS theory in the context of visualisation can be found in sub-chapter 2.3.

2.1.3 Past, Present and Future of Data Visualisation

The development of data visualisation can be divided to four phrases with the following milestones. It includes the phase of initial development (before the 1600s), emerge of measurement and graphic forms (1600s-1800s), golden age (1800s-1900s), a thriving period of modern graphics (1900s-1980s) and an intelligence period (1980s-) (Tufte, 2001; Ware, 2004; Friendly, 2006; Few, 2007; Strecker, 2012b). In this sub-chapter, the historical and present characteristics and challenges of data visualisation in different phases are reviewed, followed by a discussion the future of data visualisation.

Strecker (2012a) illustrates visualisation as a field – an integration of the understanding of visualisation and prominent characteristics in different historical stages. The root of visualisation can be traced back to the 2nd century, referred as the early stage of maps and diagrams, when ancient Egyptian surveyors used tables to record and organise the position of celestial bodies to help with the layout of a town and the creation of a navigational map (Friendly, 2006). Other evidence, such as diagram of planetary movement in 10th century (Figure 2-1), also reveals that the visualisation at the early stage was used to marking the position as well as to record the logical relation between tabulating values (e.g. timeline and positions) and plotting them for pattern identification. During the phase of initial development, also known as early map and diagram, visualisation was mainly used to mark the position and movement, which helps the users to identify a certain object, such as stars, and trace the route where the object moves to (Tufte, 2001).

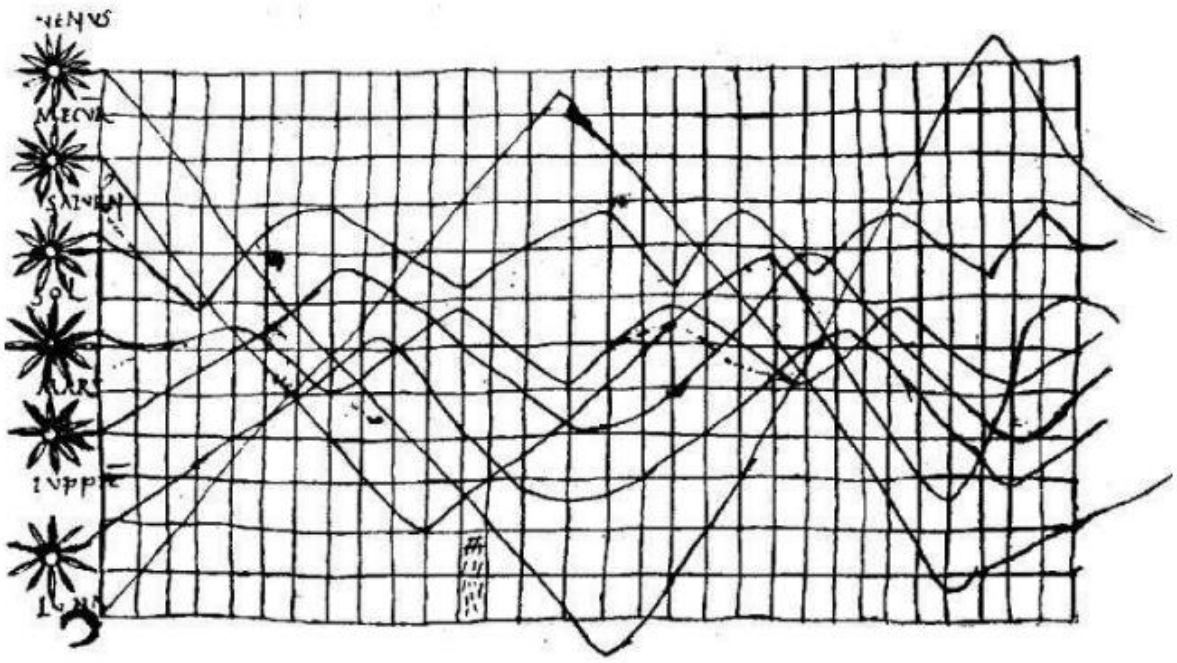


Figure 2-1 Planetary movements as cyclic inclination over time (Funkhouser, 1936; cited in Tufte, 2001*)*

Due to the development of measurement techniques, the visualisation in the 17th to 18th century was mainly concentrated on physical measurements, such as space, time and graphical distance. The development of graphics was also highlighted during this stage. Descartes' geometry and coordination systems can be regarded as appropriate examples for recording the precise positive and movement by incorporating single or multiple dimensions (axis), which are still popularly applied for plotting and scattering data objects like bubble chart. Other evidence, such as Scheiner's records of sunspots (1626) (Figure 2-2) and Langren's graph of measuring distance between Toledo and Rome (Figure 2-3), also implies that the focus on the visualisation in this stage was on measuring objects, like size, position and distance, in order to reflect the objective measure of a natural phenomenon via visually enabled comparison among different objects or time points.

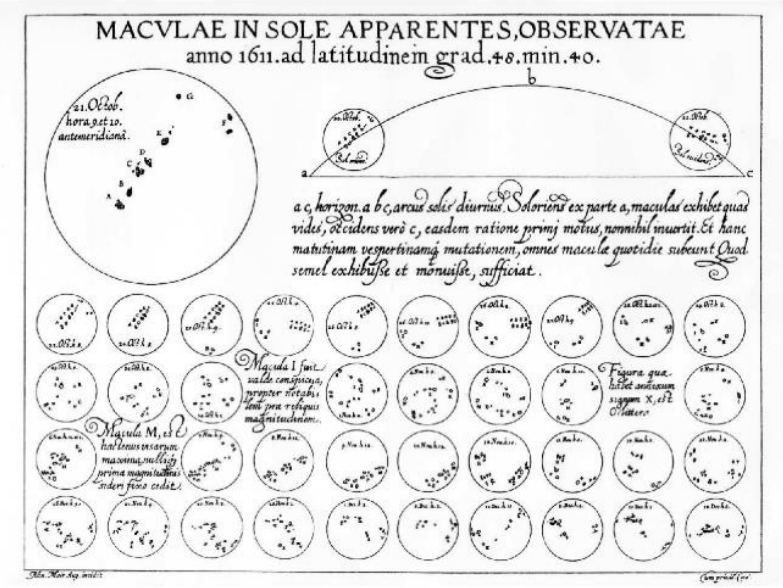


Figure 2-2 Scheiner's graphic records of the changes of sunspot over time (Scheiner, 1630 cited in Tufte, 2001*)*

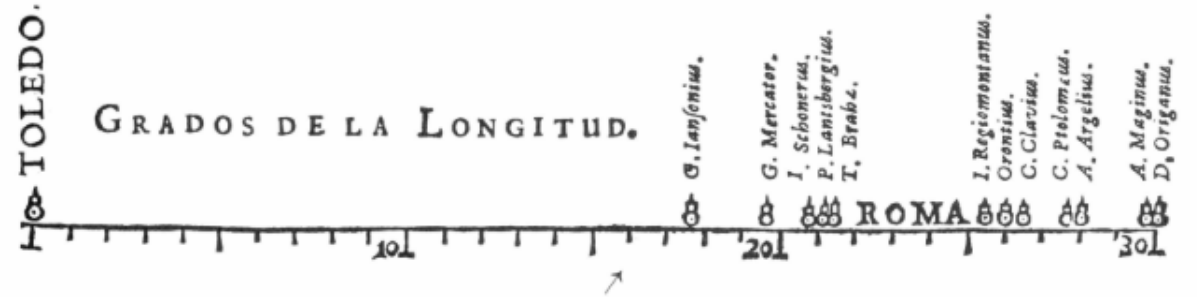


Figure 2-3 Langren's 1644 graph of demonstrating the distance from Toledo to Rome , (cited in Tufte, 2001*)*

Compared with the phase of initial development, the visualisation practices focus more on the measurement of a physical object and emphasise its accuracy. By the end of this stage, the growing interest on real life data (such as real measure of distance), sense-making theories for visualisation (like analytical rules of Descartes' geometry), and initial ideas of visual representation (like dimensions and positions) led the start of visual thinking, which encourage readers to explore the information based on the visual representations.

In the 18th century, with the aid of the development of statistics and graphic techniques, the focus of visualisation started shifting from the reflection of graphical positions and distance to portrait of more abstract data patterns, such as size, proportions and changes along timeline. The inventions of bar charts, line charts and pie charts from Playfair (1821) play very important roles in the development of visualisation in the later stages. One of most famous examples is the pie-circle-line chart from Playfair (1801), which creatively integrated diverse graphic forms for enabling the comparison of taxes and population among different dominant countries (Figure 2-4).

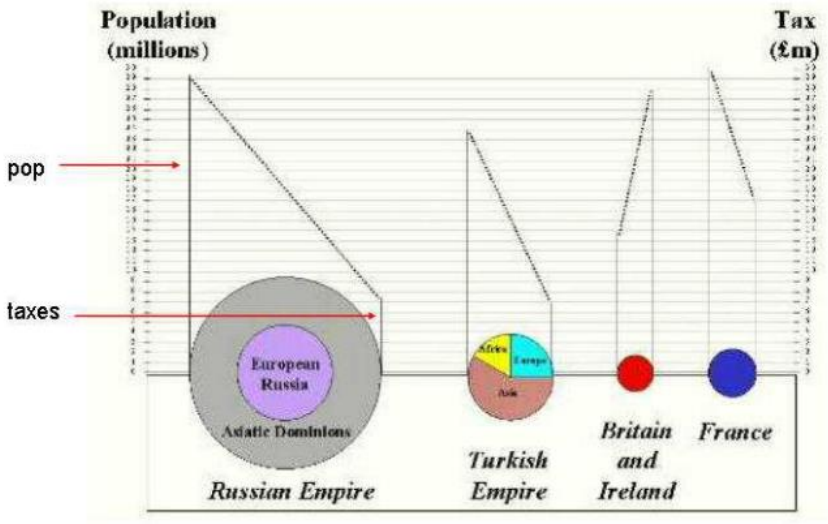


Figure 2-4 Playfair's 1801 pie-circle-line chart (comparison between population and taxes), cited in Tufte (2001)

The period from the 1800s to the 1900s is also referred as a golden age of statistical graphics where statistical techniques were popularly incorporated into visualisation to reveal more complex data patterns, including multiple dimensions including time series, geographical positions, and changing patterns of datasets. Most importantly, the visualisation at this stage started appearing the characteristics of storytelling, and gradually shifted from the directly reflection of statistical reflection of datasets. Playfair's input of graphic forms offered a wide range of tools for different authors to demonstrate the complex data as well as visual stories. Playfair (1821) utilised time line, bar and line chart (Figure 2-5) for demonstrating the price of wheat (bar) and weekly wage during the different monarchy period from 1556 to 1820, in order to highlight the argument that the payment toward mechanic workers had been improved during the final period (Wainer, 2016). Compared with the previous stage, the visualisation is the golden age, which carries explanatory and even persuasive characteristics for communicating and even amplifying authors' voices to readers.

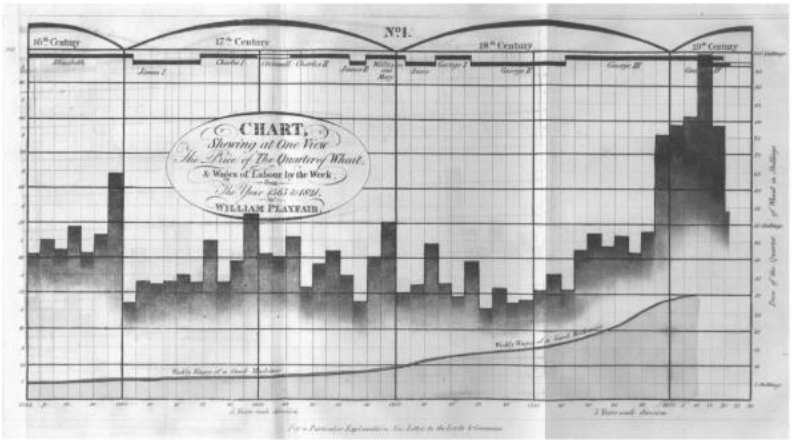


Figure 2-5 Playfair's (1821) graph of weekly wage and wheat price (cited in Tufte, 2001*)*

There are typical examples as follows. Charles Minard's description of Napoleon's campaign to Moscow (1812) with a presentation of two dimensions and different datasets, including timeline, location, temperature scale (line), strategies (light band – invasion and dark band – retreat) (Figure 2-6). It reveals Napoleon's loss of army from 422,000 men at the start of invasion to the around 100,000 when reached Moscow (Chen, 2006).

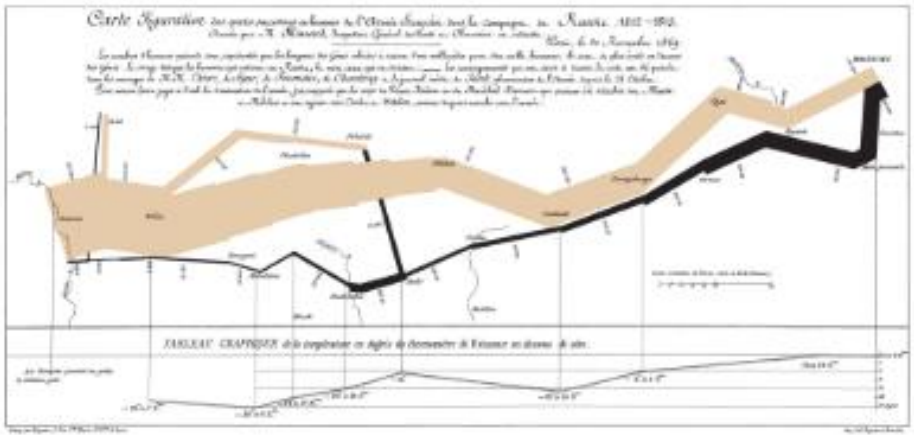


Figure 2-6 Minard's (1812) map of Napoleon's Russian invasion in 1812 (cited in Tufte, 1983)

Florence Nightingale's diagram (1857), which portrays the mortality of British soldiers and the main causes, further promoted a social campaign to improve the sanitary conditions in battlefield hospital (Figure 2-7). It was used to persuade Queen Victoria to invest in improving the condition of battlefield hospital for reducing the solider morality (Ashman and Patterson, 2015). The third example is John Snow's Cholera Map which reveals the association between the death of cholera disease and polluted water in the wells. Overall, at this stage, the focus of visualisation was no longer on producing images based on dataset, and gradually develops a sense of uncovering insights and communicate the highlighted patterns of dataset to readers with a specific purpose. It can also be referred to as the dawn of infographics, where data can be free from restriction of written words via visualisation (Bogost, Ferrari and Schweizer, 2012). It simplifies the complex dataset to visual representations for communicating the key information to the readers (Tufte, 1983).

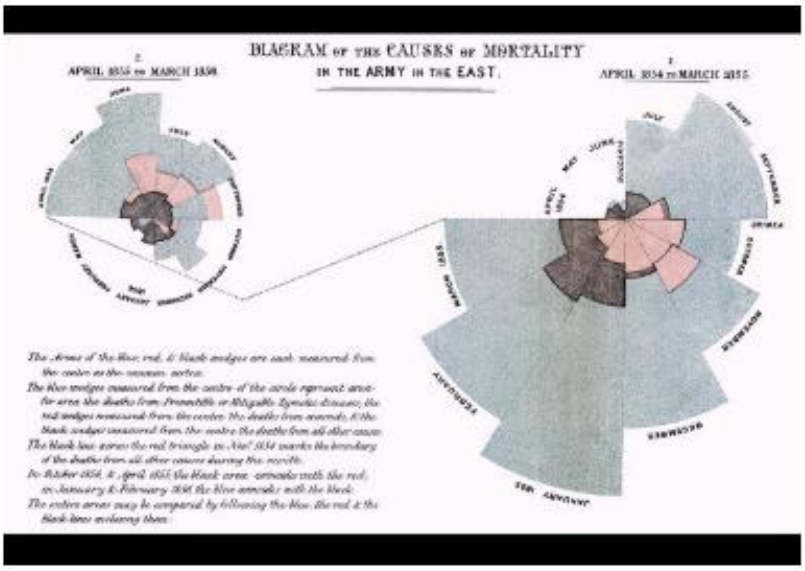


Figure 2-7 Nightingale's rose chart of British Army mortality (cited in Tufte, 1983)

The third phase refers to the thriving of modern graphics, including two stages. In the stage of "dark age" (Friendly and Denis, 2005), there were a few innovations which appeared between the end of the 1800s and around 1950, but most graphic works, like Playfair's diagrams and multiple chart view, were popularised, applied and accepted in the scenarios of research (scientific observation and analysis) and production (blueprints for infrastructure construction). The stage of "re-birth" starts at the 1960s. Tukey (1962) initials a call for incorporating data analysis techniques into graphical displays, which suggests that the visualisation should enable readers to analyse data and identify the key data patterns, known as "Exploratory Data Analysis". Bertin (1967, cited in Mei *et al.*, 2017) integrates the theory of semiology into visualisation in a formal and systematic pattern, which offers a set of guidelines of the organising visual and perceptual elements based on dataset features. In addition, with the popularity of the mainframe computer, the automated graphing techniques and interactive statistical application started to be used for developing multivariate and multidimension visualisation to communicating complex patterns in the dataset.

Since the 1980s, known as the intelligence period, with the development of in-memory processing techniques and cloud computing, computer-aid visualisation has been accessible and affordable, which allows visualisation to cover several dimensions and diverse types of datasets and to enable interactive data analysis. Therefore, the focus of visualisation gradually shifts from the presentation to communication, where increased attentions are led to relieve the perceptual and cognitive load for readers to quickly capture the key patterns and trends from the dataset. The key milestone can trace back to 1977, where Tukey (1977) defined a visual approach to analyse and explore data as Exploratory Data Analysis – making sense of data. Tufte (1983) further pinpoints the effectiveness of displaying data visually. It further points out that the envision of information should serve the purposes of communication documentation and preservation of preservation of knowledge driven by readers'

purposes, followed by a series of designing principles for visual representations. The following discussion of effectiveness improvement of data visualisation includes pre-attentive attributes for perspective load and Gestalt Law for cognitive load (Ware, 2004). In 2000, given the availability of affordable computers with a powerful graphical capacity, the concept of information visualisation is noted by Card, Mackinlay and Shneiderman (1999), to explore the dynamic, interactive, inexpensive medium of graphical computers to device new external aids that enhance cognitive abilities. It claims that the purpose of visualisation is insight not picture, and main goals of the insight are discovery, decision making and explanation.

With the advent of the smart devices and the proliferation of business software, including the excel spreadsheet, Tableau and Qlikview, one click of a mouse can transform a huge amount of data into a graph. Therefore, the research focus has been gradually moving from graphic designing and programming to the methods and processes of making sense of visualisation. It includes the sub-concepts of visual analytics, interactivity and narrative visualisation. Keim, Mansmann and Thomas, (2010) portray visualisation as a compound concept, consisting of visualisation development, visual analytics and interactive modelling. Visualisation development refers to the transforming of data from the numeric format to a visual representation, where the key patterns and trends can be revealed via the visual cues and techniques for improving the convenience and directness of readers' perception and interpretation. Visual analytics refers to the process where readers make sense of data via observing and interacting with the data visualisation interface (Keim, Andrienko, J. D. Fekete, *et al.*, 2008). It combines human intelligence and graphic techniques and realises the alignment and collaboration among readers' information needs, authors' thought of visualisation development and experts' knowledge input. Finally, the concept of interaction plays the role of enabler, which supports the interactive function to facilitate the further address of readers' intentions as well as the context of interpretation, corresponding to the concept of micro/macro reading from Tufte (2001).

Chen and Golan (2016) define visualisation as a form of information processing, enabling the transformation of information from one representation to another. It can further include four levels of visualisation tasks. The first level is disseminative visualisation, which indicates a presentational aid for disseminating information or insight to different individuals. The analyst mainly delivers the key information to the audience without provoking any further questions in this task. The second level is observational visualisation, which associates an operational aid that enables intuitive or speedy observation of captured data. In this task, the design of visualisation should be able to respond to the "what-if" questions from readers, to examine the results under different conditions. The third level is analytical visualisation, which links to an investigative aid for examining and understanding complex relationship among different data entities, including correlation, association and causality. More interaction between users and visual representations are utilised for examining the relationship among observed variables via various statistical methods. The final task is model-developmental visualisation

where users can incorporate their mind model, including their understanding of decision-making rationales and awareness of decision-making context in visualisation. In this task, users will be empowered to improve the existing model as well as to create a new model which can further fit the real-time scenarios, which echoes the statement of information fulfilment "right information at right time point to a right person for fulfilling a right demand" (Tan, Abdaless and Liu, 2018).

Bai, White and Sundaram (2011) proposes a definition of purposeful visualisation, which reveal the underlying rationale to visualisation i.e. that visualisation should fulfil a particular purpose for one or more stakeholders within a certain context. The stakeholders include designers, viewers and presenters. Designers mainly concentrate on making and modifying the visual representations and interactive functions for addressing the theme-related requirements, issues, objectives and activities. Viewers associate with the role which provides the requirements of visualising data and make sense of data via visualisation. Therefore, they are the main characters whose requirements, preferences, cognitive features, pre-knowledge, and decision-making models will affect the design of data visualisation. Presenters work as a coordinator between designers and viewers. They will help with the interpretation on the viewers' side and requirement understanding on the designs' side.

It is gradually being recognised that the challenge of producing an appropriate data visualisation is for the developers and analysts to understand data as well as users' demands. The main purpose of producing data visualisation is to enable users to accomplish their task; in other words, making sense of dataset to lead the following actions with a certain purpose and in a certain context (Koh *et al.*, 2011). User play a central role during the visualisation development for inputting their demands, preferences, purposes and contextual information for sense-making. However, as pointed out by Thomas and Cook (2006) and Sacha *et al.* (2014), although visualisation construction can be easily assisted by automated software such as Tableau or Qlikview, it often suffers from insufficient information of users and corresponding tasks. Therefore, it is necessary to find new methods of constructing visualisation with engagement of users during process and to deliver a better targeted result.

In summary, the team "data visualisation" has existed in human history for a long period time, which can be traced back to five main development periods of visualisation. The development focus shifted from identifying an object (initial development), to measuring a phenomenon accurately (measurement and graphic form), to communicating key information purposefully (golden age), to incorporating exploratory analysis (modern graphics), and to intelligent systems for adapting to users' demands (intelligence). Inspired by Aigner *et al.* (2007), data visualisation can be portrayed as an integration of three components (Figure 2-8), including visualisation (construction of visual representation), analysis (exploratory and explanatory analysis) and user (tasks, preference and context). In the past, three main compositions were often researched in a separate pattern due to the insufficient computing capacity for involving a wide range of users and facilitating the adaptable analytic techniques. Therefore, as

commented by Ware (2010), visualisation was usually "one size for all". With the development of human-computer interaction and in-memory visualisation automation, the interaction with visualisation can be implemented via "mouse-click", and therefore the social part of visualisation development, such as users' tasks, perception and cognition demands, and a context for sense-making were underemphasised. In the future, the position of users will be centralised during the process of visualisation development, and the main challenge will shift from the visualisation techniques to the social interaction among different stakeholders, such as bridging the knowledge gaps, collaborating for developing the visualisation, and process and activities of eliciting, documenting and managing users' demand during the process.

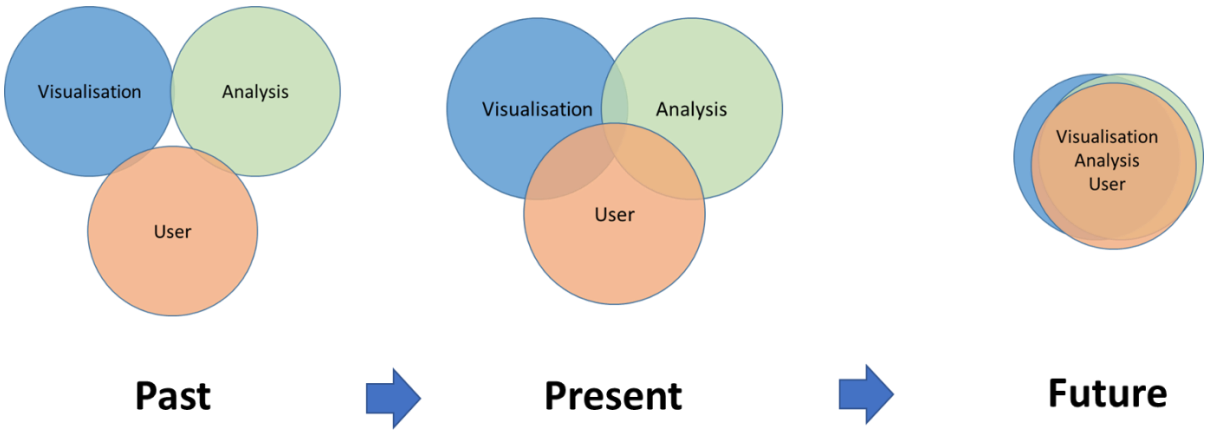


Figure 2-8 Evolutionary view of visualisation (adapted from Aigner *et al.* (2007*)*

2.2 Visualisation Systems, Principles and Components

2.3.1 Visualisation Systems

Visualisation is a complex process involving the efforts from human and machine processing capacities. It can also be portrayed as an integration of different systems to collaborate for sense-making (Janvrin, Raschke and Dilla, 2014). Kahneman (2012) interprets the information processing of visualisation via introducing the term system 1 and system 2. System 1 refers to the human perception of visual representations where the sub-conscious minds of human can generate a rapid and intuitive impression e.g. colours and clusters of objects. It is associated with the pre-attentive attributes and Gestalt rules, which help users quickly capture the patterns shown on the visual representations. System 2 refers to the human cognition of visual representations where the conscious minds of human can think further of the meanings conceived in visualisation with the aid of prior knowledge, purposes and contextual information e.g. calculation and reaction. It is associated with the visualisation comprehension and sense-making, which lead users to extract information from the visual representation and configure the following actions correspondingly. Two systems are intertwined where system 1 feeds perceived

information to system 2 for further comprehension (Kirk, 2016). Therefore, for visualisation development, it is important to make the visual representation easily and accurately perceived (system 1) and to reduce the cognition workload of understanding and analysing data (system 2).

Visualisation consists of four different levels with different purposes and user context (Chen and Golan, 2016). The first level is disseminative visualisation (V_d), which mainly contributes a presentational aid for disseminating or delivering information and insight to different users. On this level, the purpose and interpretation focus have been very clear without the necessity to address the complexity of dataset. The analyst mainly focuses on delivering key information when performing a visualisation task. The second level is observational visualisation (V_o), which mainly contributes an operational aid for provoking intuitive and quick observation of presented data. Chen and Golan (2016) also point out that the observational visualisation is a part of routine operation of analysts, which can constitute an initial stage where users can obtain a quick view of data patterns and which leads them to further interpretation. The third level is analytical visualisation (V_a) which mainly contributes an investigative aid for understanding and examining the complexation data patterns, such as correlation and causality. It can help with demonstrating the potential causal relationship with the focal data objects, for the purpose of addressing all possible reasons behind a certain phenomenon. Therefore, an underlying challenge is to prioritise the users' investigative effort with an analytical model. The fourth level is model-developmental visualisation (V_m), which mainly contributes a developmental aid for further as well as continuous refining of the existing models. Alternatively, the analyst can create a new data model based on the users' questions. Different from the visualising a data pattern, the model can reveal the process of answering users' questions, which enables analysts to adapt the results in different conditions and inputs.

Other than four levels of visualisation, Chen and Floridi (2017) point out five main components of data visualisation for facilitating the four data visualisation levels (Figure 2-9). The first component is machine processing (M) which generally refers to the computational process executed by computers, including statistical measures and data analysis. Each computing process constitutes a model for serving a specific users' question. The second component is human processing (H) which refers to the human recognitive processes including a series of activities engaging users. It contains instance identifying, visualisation viewing and information reasoning. The third component is visual mapping (M) where the data can be transformed to visual representations for purpose of being viewed by users. It involves a purpose-driven process where visual representation would be mapped to users' information demands as well as interpretation purposes. It can also act as a bridge between machine processing and human processing through visualising the analytical results from computation to users for interpretation. The fourth component is interaction (lines start from H), referring the activities of enhancing the engagement of users for inputting or upgrading their information demands. It includes typical interactions in visualisation, such as adjusting conditional parameters and refining analytical models. It is not regarded

as a separate component, but connects the other components of machine processing, human processing and visual mapping. In other words, it can be driven by human processing components, such as demands and purposes, and generate impacts on machine processing components (e.g. analytical model) and visual mapping (e.g. chart and diagram selection).

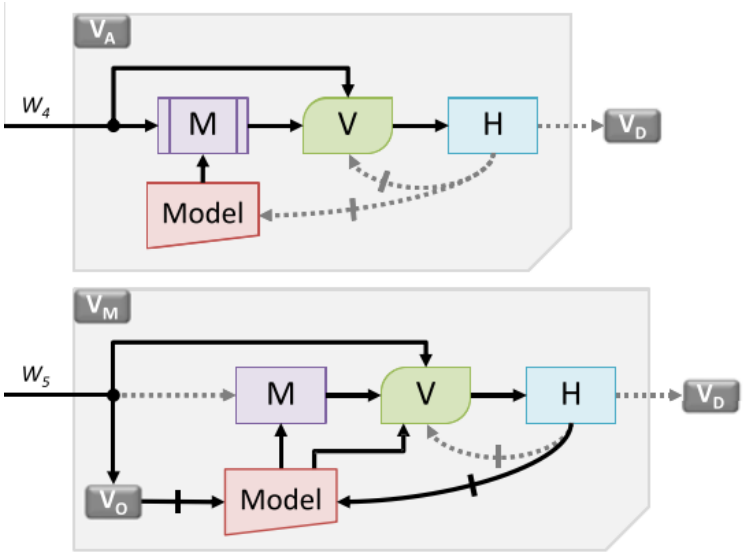


Figure 2-9 Examples of visualisation workflows (Chen and Golan, 2016)

2.3.2 Rules of Data Visualisation Design

Other than the process and components portrayed in Chen and Golan (2016), it is essential to incorporate the rules of design for assembling visual representations to reveal the data patterns.

Bertin (1977) sets two basic forms of data, including data value and data structure. It indicates the communication of data should not only focus on reflects its value or content, but it should also reveal the relationship among different value, such as correlation or cause-and-effect relationship. Bertin (1983) further develop the two forms of data to a set descriptions of visualisation properties and application rules, which is known as "Semiology of Graphics". Specifically, he defines the component in a system of graphical signs as visual variables and categorise them to three levels, including qualitative, ordered and quantitative level. First, qualitative level includes two perceptual approaches, including association to identify the similarities among data values and selection to identify the differences among them. Associative perceptual approach (≡) can be used to pinpoint a characteristics and group of data values with the same characteristics, while the dissociative (or selective) perceptual approach (≠) can be used to differentiate them to different groups based on different characteristics. Second, ordered level (O) focuses on ranking data values for a purpose of comparison (e.g. more than or less than). With the aid of graphic sign, the order among data values needs to be universally perceptible. Third, quantitative level (Ø) refers to the usage of countable units, such as numeric ratios, for identifying the differences

among data values in details. Therefore, the size is very often used as main visual variable to symbolise the quantitative differences.

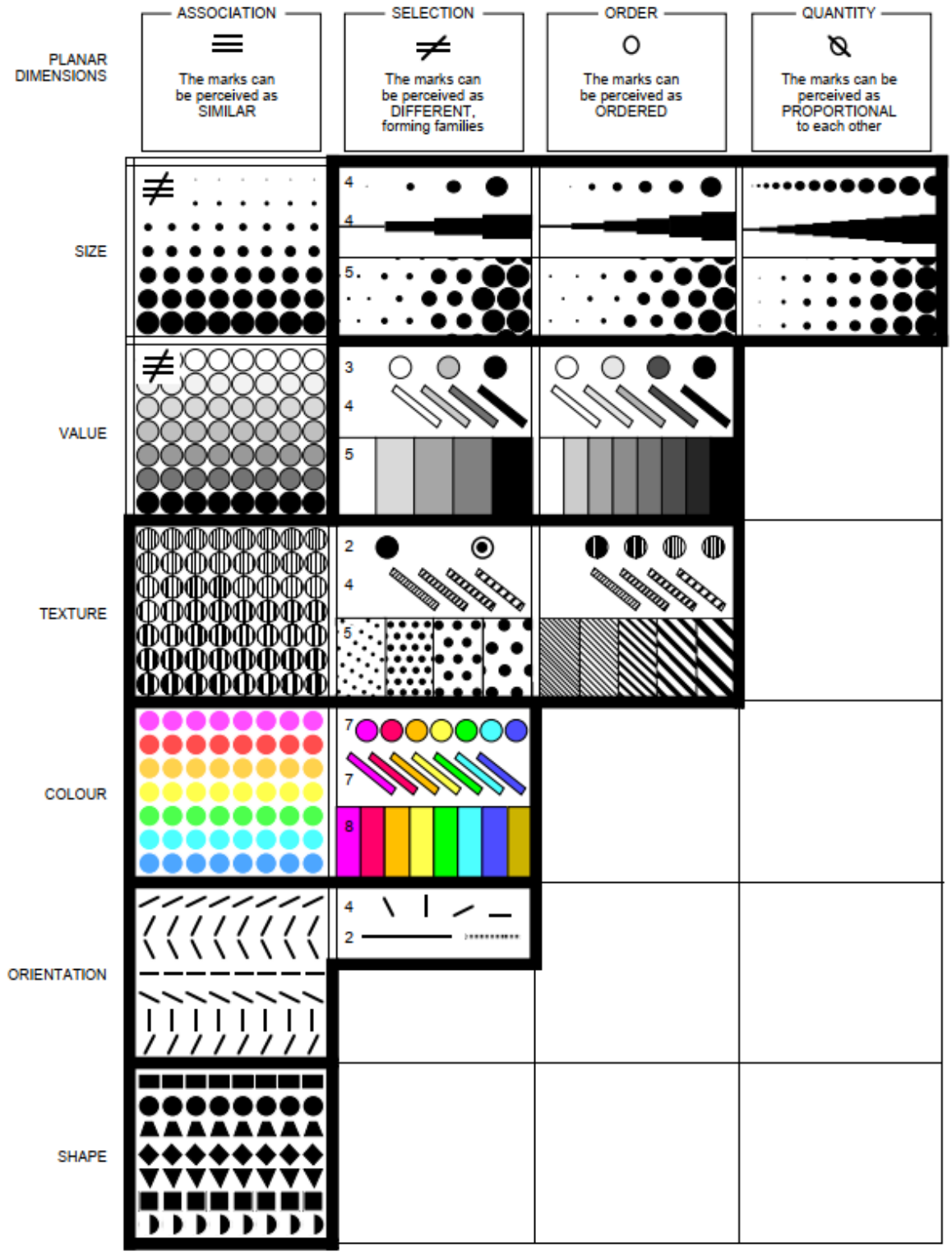


Figure 2-10 Illustration of Bertin's Visual Variables

Bertin (1983) shifts the research focus of graphic sign from reflecting data values to indicating the data structure. The categories of visual variables help identify the purpose of applying different visual

variables in the visualisation design, which establish a set basic grammar of visualisation development. However, there is merely six basic visual variables incorporated in Bertin (1983), including size, value, texture, colour, orientation and shape. The combination of visualisation variables, which constitute functional diagrams and charts, has been more often used in the practice for indicating data structure in multiple dimensions. For example, bubble chart can include all seven visual variables, and meanings it conveys is more complicated than a single type of visual variable. Therefore, Bertin (1983) initialises the basic categories of visual variables, but more rules and principles to guide and government of integration of visual variables needs to be further developed.

Referring to Ware (2010), there are three main sets of design principles for guiding data visualisation, including Melissa Anderson's Principles of Design with a focus on evaluating the quality of visualisation design (incl. balance of visual components, emphasis of data patterns and so on), Gestalt Principles of Design with a focus on the association of pre-attentive patterns and indicated meanings, and Tufte's 7 principles of design with a focus on decluttering of data visualisation. Since in this research, the main focus is to discover the means of facilitating the users' understanding, interpretation and sense-making of datasets, Gestalt Principles will be reviewed to understand the association of visualisation patterns and related meanings, and to explore the possibility of incorporating it into the visualisation development framework.

Gestalt principles refers the general rules of organising perceptual items. It facilitates the visual perception processing by revealing the indicated meanings of data representations, such as proximity and similarity (Peterson and Berryhill, 2013). Based on Huang (2014), the features of visual perception are generic to some extent, which means that without being taught, the users can generate their initial interpretation in a quick pattern. For example, the visual objective with similar shape and colour will be grouped together during the perception. Therefore, the data objective within the same category can be set in the same colour or shape to symbolise the categorical relationship, such as a group or cluster of market segment with a similar consumer behaviour pattern.

Overall, in the Gestalt principle, although their interpretation and application may vary across different research, 10 major principles have been generally acknowledged in the research of data visualisation, including proximity, similarity, enclosure, symmetry, closure, continuity, connection, figure and ground (Table 2-1).

Table 2-1 Gestalt principles in visualisation development (Koffka, 1935, cited in Ware, 2010)

Principle	Description.
Proximity	The distance among items can be utilised to signify the relationship of "being grouped" or "being separated"
Similarity	Objects appeared with a similar pattern (e.g. shape or colour) are instinctively viewed as "bring grouped" in our minds
Enclosure	Objects which take a part of a closed figure tend to be viewed as a group
Closure	Readers always focus on a recognisable pattern. Even if some of elements might be missing, human brain will fill the blanks and complete the image

Continuity	Objects placed on a line are viewed as "being related" than others not on the line
Symmetry	Deploying objects in a balanced pattern can make pattern comparison easier
Connection	Link elements together via using lines or ribbons for signifying the relation among objects
Figure and ground	Focus only one out several objects; the key object is the figure, and everything else are perceived as the "background". It can help highlight the interested pattens of datasets and prevent the noise from the irrelevant patterns

2.3.3 Chart Selection Principles

In addition to the data visualisation design rule, the matching between interpretational purposes and visualisation representation is also key for accurately addressing users' information demands. Referring to Schwabish (2014), it discovers the relationship between visualisation forms (interactive or static) and functions (explanatory or exploratory) (Table 2-2).

Table 2-2 Forms and function of data visualisation (Schwabish, 2014)

Form	Function	Explanation in the context of visualisation.
Static	Explanatory	Chart or infographics for identifying, communicating and reinforcing key findings from data.
Static	Exploratory	Charts and diagrams for reflecting the experiment results for further analysis e.g. Musli ingredient network for relationship discovery.
Interactive	Explanatory	Online slides show which allow for reading the story line in different sequences.
Interactive	Exploratory	Intelligence visualisation interfaces, such as BI dashboard, facilitate the information exchange between readers and authors (or servers if automated).

Berinato (2016) further develop the classification with a new consideration of information feature. visual representation can be categorised based on two dimensions, including interpretation purposes (exploratory or declarative) and information feature (conceptual or data-driven) (Figure 2-11).

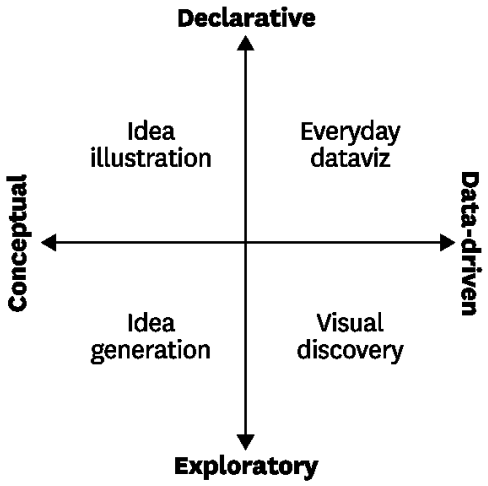


Figure 2-11 Four types of visual communication (Berinato, 2016)

There are characteristics of four quadrants. The first quadrant is idea illustration with a type example of process map. It focuses on simplifying, structuring and communicating authors' ideas to the readers. The second quadrant is idea generation with an example of mind map. It focuses on interacting with

participants and exploring an innovative solution for a certain problem. The third quadrant is visual discovery with an example of data dashboard. It focuses on facilitating analysis, making sense of observed data patterns, and examining hypotheses/exploring new trends. The fourth quadrant is "everyday dataviz" with an example of static chart. It focuses on pinpointing and communicating a certain data pattern in a predefined context to the target readers. In the practice, the visualisations on four quadrants are not distinct, but are integrated to serve the users' demands. For example, the dashboard in the visual discovery quadrant might need to incorporate a static chart at the beginning for the purpose of letting readers establish an initial view of dataset, and then gradually reveal more details by drilling down a certain data object.

Abela (2008) proposes a diagram for chart suggestions based on the visualisation purposes, including comparison, distribution, composition and relationship (Figure 2-12). Comparison refers to showing differences and similarity among data values (bar chart for comparing items and line chart for comparing time points); distribution refers to displaying frequency, grouping and spreading of data objects (Histogram on different amount of dimensions); composition refers to showing the relationship between the parts and the whole (stack chart for part-whole relationship over time and pie chart for the proportion of components); relationship refers to identifying the relationship like correlation and distance among data objects (scatter chart for trends finding and map for location). Abela's work offers to a preliminary guideline to select charts based on the purposes of interpretation. Users can follow the selection tree, starting with the purposes, then the data features (number of variables, time point or time series, and high or low dimensions), and finally link to the candidate charts.

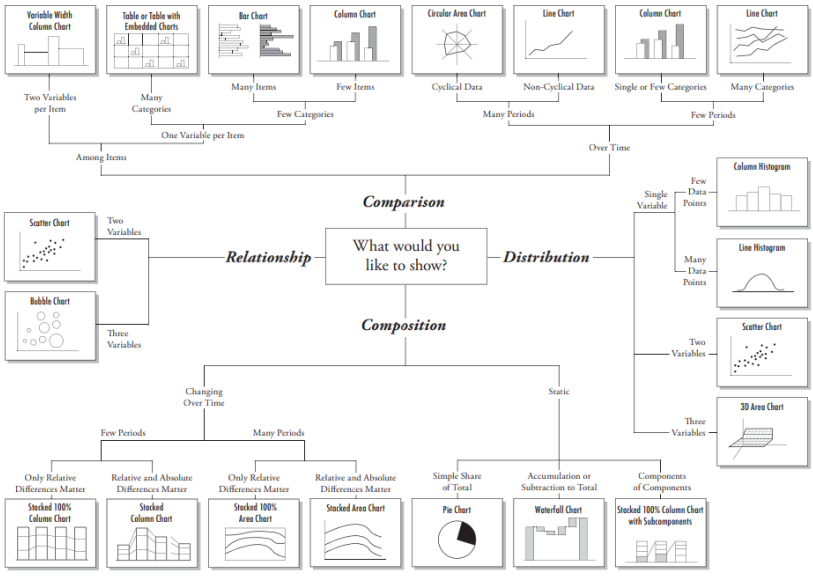


Figure 2-12 Chart suggests: a thought starter (Abela, 2008)

2.3.4 Interactivities in the Context of Visualisation

Interaction plays a vital role in visualisation. With the development of cloud computing and in-memory computing, users can access to the visualisation (e.g. dashboard in the business intelligence) via a web browser and visualisation can quickly respond to the uses' requests in terms of what to display and how to display (Stodder, 2013; Thoo and Randall, 2015). With the interactive functions, the users can also explore the visual representations to configure different answers to different questions with different purposes in different scenarios. Referring to Yi *et al.*, (2007), visualisation consists of two components, including representation and interaction. Representation is related to computer graphics to transform data to representations and to deploy representation in a visual display. Interaction is related to human-computer interaction (HCI), which refers to the dialogue between users and visualisation artefact (even the developers) for exploring the data to configure a deep insight. Ware (2012) claims a good visualisation should allow users to drill down for finding more data which is important to them. Every data representation in the display needs to active and capable of highlighting the data on in need, hid the irrelevant data, and respond to the users' demands for facilitating the sensemaking.

When it comes to the HCI theories, the interaction design process consists of four basic activities, including requirement discovery, alternatives design, prototyping, and evaluation (Preece, Sharp and Rogers, 2015). Firstly, interaction starts with gathering and understanding users' requirements, including whom they are and what support they seek from the interaction. Secondly, alternatives design allows users to be engage with the conceptual model design where they can further refine their functions and concrete design where they clarify what they can do with interaction. Thirdly, prototyping enables users to feel and interact with the initial version of artefacts, which give them a direct view of what interaction can offer. Fourthly, the evaluation will focus on measuring usability and acceptability based on user-experience criteria and see to what extent the interaction can fulfil users' demands. However, the four steps should be pleased in a linear process but an iterative process, which is known as interaction design lifecycle model. It indicates the updated users' requirements and feedbacks can continuously improve the design of alternatives and prototype in order to the further understanding and fulfilling users' demands. The generic interaction design method also aligned with BadIdeas Methods (Silva, 2010) and Interaction Design Integrated Methods (IDIM) . BI emphases the iterative nature in the interaction design method, where the initial bad idea can be continuously polished to fit to the users' demands. IDIM then recognises the incorporation of knowledge base (Filippi, Barattin and Cascini, 2013). It indicates that interaction design should not only focus on the requirement articulation but also the exploration and development of users' knowledge.

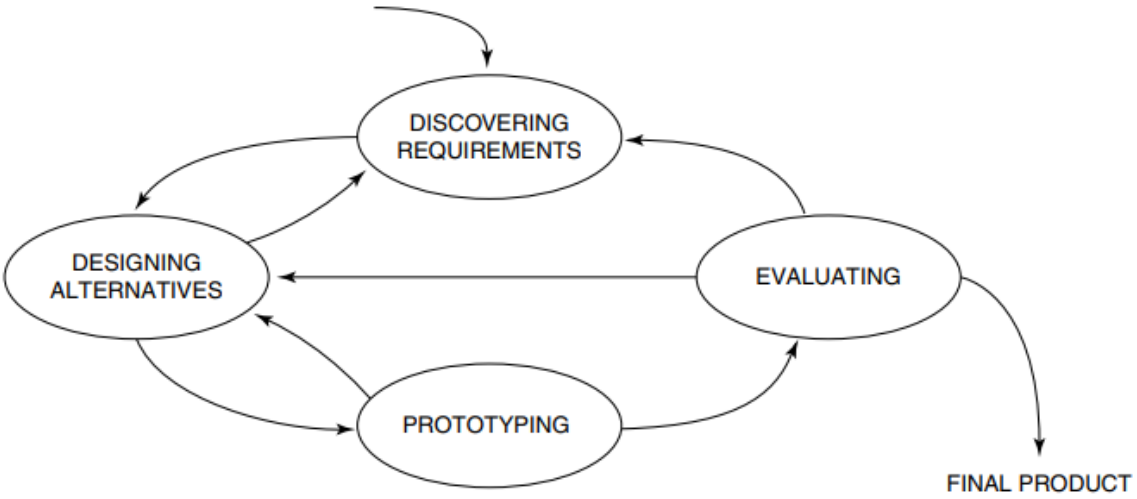


Figure 13 Interaction Design Integrated Methods (IDIM) (Filippi, Barattin and Cascini, 2013)

In comparison with the traditional static visualisation, such as infographics and automated displays, the interactive functions of visualisation has advanced the exploratory features of visualisation. Commented by Tufte (2001), with the growth the data volume and complexity, more visual representations are incorporated into a display. Therefore, users express a growing demand to manipulating the visual display by highlighting and filtering data for aligning the display with their sensemaking. Spence (2007) further raises the concept of "passive interaction" which means the users' mental model of making sense of data can be updated or enhanced while reading the visual representations. They will, therefore, adjust the visual representations for fulfilling their information demands. From the perspectives of perception and recognition systems, it is pinpointed that interaction can help overcome the limits of visual representation and amplify the recognition (Few, 2013; Perdana, Robb and Rohde, 2018). It is corresponded by the concept of "user-centric visualisation" (Elias, 2012), where other than visualisation forming techniques, interaction helps reveal more of the human aspect as well as the social aspect of visualisation. Information demands, interpretation tasks and sensemaking context vary among different individuals, and thus visualisation needs to be interactive to customise the view for each user.

In terms of the categories of interaction, there are different descriptions in prior studies. Shneiderman (1996) proposes the famous "Shneiderman's mantra of visualisation" that "overview first, zoom and filter, then details-on-demand". It reveals that with the aid of interaction, visualisation becomes a process where users can read the visual representations layer by layers for finding out more information and relevant information. Keim (2002) categorises interaction into five types, including dynamic projections, interactive filtering, interactive zooming, interactive distortion, interactive linking and brushing. Ware (2012) further clarifies three loops of interaction. The lowest level is the data manipulation where users can select and move the data objective by the basic hand-eye coordination. The intermediate level is the exploration and navigation loop where user can form their mental model

of making sense of data, including identifying the relevant data objectives and path among them for navigation. Different sequence of reading can be corresponding to different interpretations and different knowledge exploration. The high level is problem-solving loop where users can form a hypothesis and refine them for an augmented visualisation process that basically align with the abductive reasoning process for continuously refining the understanding of data while interacting with data representation. In this research, the interaction category from Yi *et al.* (2007) is mainly applied in this research, including seven major categories of selecting, exploring, reconfiguring, encoding, elaborating, filtering and connecting (Table 2-3).

Table 2-3 Seven types of interactivities in IDV (Yi *et al.*, 2007)

Interaction type	Explanation in the context of IDV
Selecting	Highlighting the relevant data objects/patterns based on users' demands and keep track of them when in a changing/time-series view
Exploring	Examine different subset of data objects with a more detailed view for viewing the data sets for seeking a deeper insight or from different perspectives
Reconfiguring	Changing the spatial arrangement for revealing the data patterns from different perspectives, like different associations and clustering relationship of data objects
Encoding	Altering the visual appearance, like size, shape and colour, for uncovering and communicate the relationship among different data objects to multiple users. User can also define the embedded social meaning to the visual appearance, like traffic light colours for indicating normal, warning and emergence.
Elaborating	Altering the representation on different layers, from overview to a focal point of data objective, as well as the navigating path in-between. It enables users to control more or less detailed in display
Filtering	Reduce the data objects in a display for easing the cognitive load without affecting the original datasets
Association	Establishing association across different visual representations, via highlighting the connection among different representation for constructing a storyline, and revealing the hidden details when a specific data object is selected

2.3 Semiotics in Visualisation: From A Visualisation Perspective

Organisational semiotics, a doctrine of sign, reveals the process where information is delivered from one party to another (Stamper, 1973). It also defines the technical and social factors which influence the effectiveness of communication (Stamper *et al.*, 2000). Thus, in this section, the process of data visualisation will be discussed through the model of semiosis and semiotic ladder.

2.3.1 Semiosis in Visualisation

The Theory of Semiosis was proposed by Peirce in the 1930s, which explains the process of information transfer among different parties in a triangular model (Liu, 2000) (Figure 2-14). Sign, shown as the firstness, means physical tokens used as carriers of information. Then, the authors, also known as information senders, expect readers to associate the sign to a designata, which is shown as secondness, for the purpose of enabling the reader to perceive the information carried by the sign. However, the associate (between S and O) does not generally exist but needs to take help from the intepretant (thirdness), which means interpreting the sign with prior knowledge and contextual information.

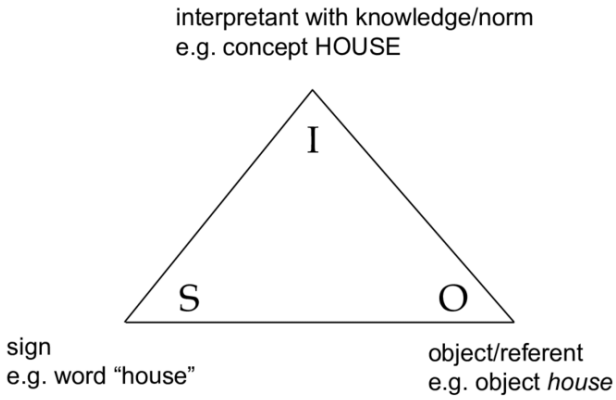


Figure 2-14 Semiosis and sense-making (Liu, 2000)

Data visualisation follows the same process. In firstness, authors design the visual representations, such as diagrams, to deliver the information (secondness) to readers. However, the information perceived by readers will be influenced by interpretant (thirdness), where the reader will take account of not only the technical aspects of sign itself, e.g. physical quality, but also other social factors, e.g. meanings, intentions and social norms. Different from the other research solely focusing on the technical aspects of visualisation like visualisation programming and algorithm development, Liu and Tan (2015) points out the significant impact of social factors on data visualisation with a model of shared semiosis (Figure 2-15). Although there is a shared sign (e.g. visual artifact) between producers and users and a shared semiosis process of interpreting signs, due to different semantic background (e.g. various understanding of visual artifacts), intentions and interpretant (e.g. context for interpretation), they will generate different intended meaning and interpret different effects towards their following behaviours. An

consistent understanding needs to be built between the author and the reader for the purpose of ensuring that authors to understand the what and how data to be visualised, what purposes to be served and what context to fit in. Segel and Heer (2010) discuss the interoperation between readers and authors in the social context and how an agreed story line can help with aligning the interpretation between both sides. Vickers, Faith and Rossiter (2013) state the one of main goal of adaptive visualisation also corresponds to the social context where users interact with the visual interfaces.

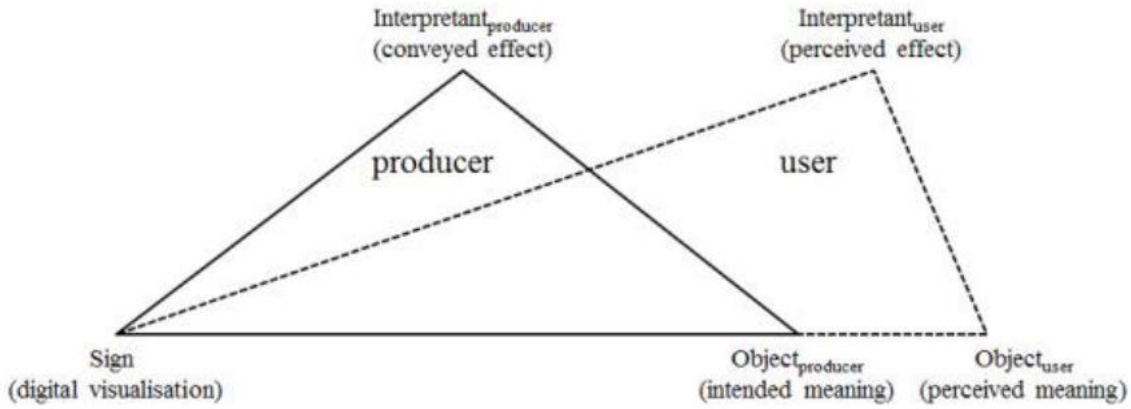


Figure 2-15 Shared semisis process between author and reader (Liu and Tan, 2015)

The interpretant is closely associated with the social environment where users are engaged with the visualistion, such as culture, decision-making context, and external pressure from other stakeholders. Compared with technical factors, such as variables and techniques of IDV development, social factors convey the characteristics of ubiquity, diversity and uncertainty. For example, an ascending line of charity surplus figure can be interpreted as a positive sign for showing healthy financial situation to sustain the long-term development. However, it can be regarded as negative sign where the charity cannot make the best use of raised fund to the charity purposes and the fund should be reallocated to other charities in need. Thus, for the purpose of discovering the mysterious impact of social factors in data visualisation and the unveiling of their impact, the framework of semiotic ladder will be discussed in the following section.

2.3.2 The Framework of Semiotic Ladder

Zooming in the box of "interpretant", the framework of semiotic ladder contributes guidelines to look for technical and social factors which might impact the communication with sign. Semiotics traditionally analyse the interpretation of sign through three levels, including syntactics, semantics and pragmatics. Stamper (2001) extends this traditional framework to six levels by adding physics, empirical and social world, which is called the semiotic ladder (Figure 2-16). In other words, compared with the traditional framework, the semiotic ladder suggests that readers take the infrastructure into account when designing the information system. Liu (2000) further develops the framework by shifting the focus to the social aspect and propose a series of methodologies to capture the users' requirements.

Socially-aware design, proposed by Liu, Nakata and Harty (2010), has followed the same research principle, and describes the process of involving users' explicit and implicit demands and social norms into the application development.

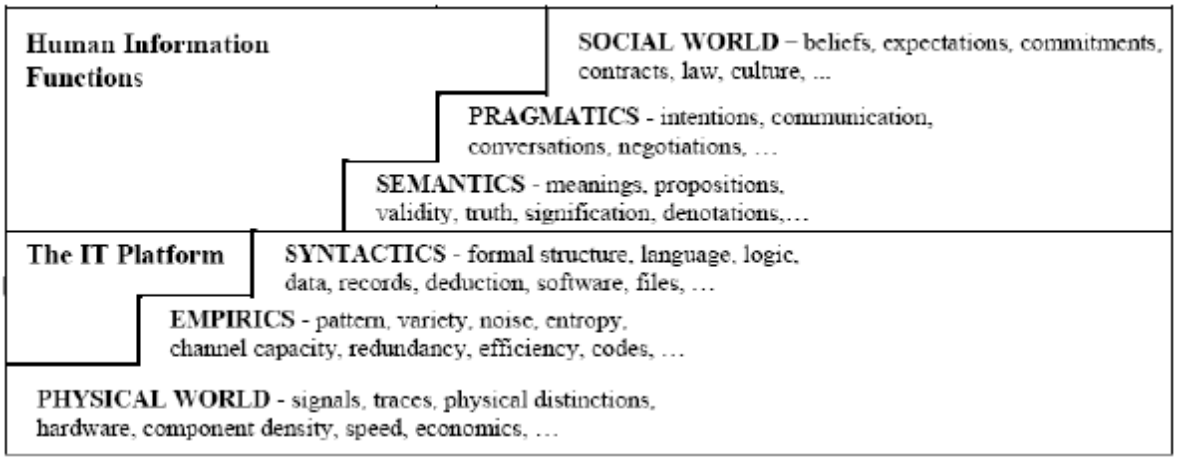


Figure 2-16 Semiotic ladder (Stamper, 1973 cited by Liu, 2000*)*

It can be adapted into data visualisation. Referring to Salter and Liu (1985), compared with technical issues, social factors might place more significant influence on the effectiveness of data visualization. As suggested by Liu (2000), other than the physical devices and program, the research focus of data visualization needs to not solely be placed on technology, but the methodology and philosophy behind it, including the semantic meaning of visual representation, the capacity to react to users' dynamic demands and intention, and the fitness of social norm where business users rely on the present data analysis findings and communicate with other stakeholders. Inspired by French, Springett and Liu (2006) who addresses the concerns of e-service trust on the each layer of semiotic ladder for locating the specific issues and configuring a holistic solution, the concerns related to the sense-making capacity of data visualization will be divided to following six layers.

- Physical world: whether visualisation development facilities as well as data sources are available.
- Empirics: whether the visualisation can be cleared, accessed and presented by users.
- Syntactics: whether users are familiar with the layouts, design codes and reading skills of visual representations.
- Semantic aspect: whether information is shown based on the shared premises (understanding).
- Pragmatic aspect: whether the presented information can be aligned with readers' interpretation purposes.
- Social norm: whether the visual representations can be sense-making in a given context and lead to the following actions.

Even though the semiosis and framework of semiotic ladder offer guidelines for designing data visualisation with consideration of both technical and social factors, they do not provide the specific process to lead the visualisation development, especially how to align the information of users'

information needs, interpretation purposes and context of sense-making. Thus, inspired by Tiercelin (2005), the abductive reasoning process will give a different insight where users might continuously build or refine their understanding and address new demands while being engaged with visualisation. Therefore, it is important for developers to master a method to acquire and manage users' requirement during the iterative process of users' engagement.

2.3.3 Requirements Engineering

Requirements engineering can be defined as a set of activities to identify the stakeholder's demands and requirements and to specify them to the detail and agreed requirements that support the design and establishment of information systems (Siddiqi and Shekaran, 1996). Kotonya and Sommerville, (1996) refer the definition for BCS (British Computer Society) which defines 'requirement engineering' as a set of important activities to identify the stakeholder's goal and to demonstrate them into precious statement of desired functions and services.

It is not a single phase, but a process to identify the stakeholders, elicit requirements and expectation, analyse and validate the requirements, and to document and specify them for support the implementation of system establishment. Also, it requires the involvement of multi-stakeholders, including both the internal stakeholders, such as system users, and the external stakeholders, such as system beneficiaries. In addition, it covers both functional and non-functional requirements. Functional requirements indicate the specific behaviour and function desired in the information system. Non-functional requirements refer to the detailed criteria to evaluate the performance of information system. Thus, requirement engineering is a set of essential activities in system engineering, which enables it to hear the voice from stakeholders through the whole procedure of system establishment. Inappropriate requirement engineering would cause the failure of project in terms of cost, schedule, quality and user's satisfaction.

Kotonya and Sommerville (1998) propose a framework to demonstrate the whole procedure of requirement engineering (Figure 2-17)

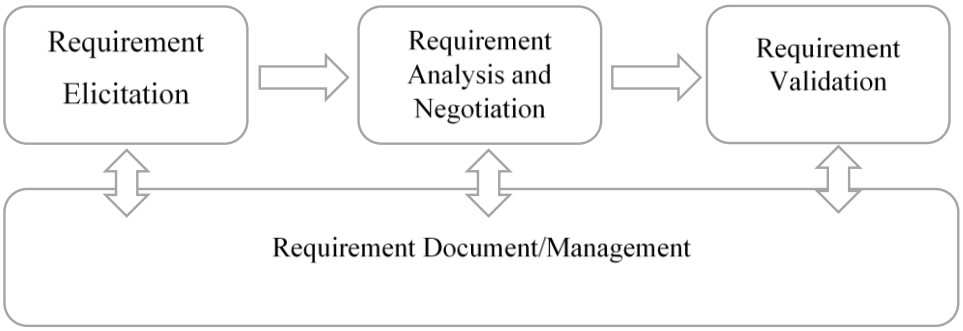


Figure 2-17 Framework of requirement engineering procedure (Kotonya and Sommerville, 1998)

In the framework of requirements engineering above, the procedure of requirements engineering can be divided into four parts. Requirements elicitation means capturing the stakeholder's expectation and requirements through consulting and interviewing all sorts of stakeholders. Then, requirements analysis and negotiation indicate scheduling a focus-group meeting to eliminate the ambiguity in the requirements and reach an agreement to ensure that the requirements are accepted by different stakeholders. Eventually, requirement validation implies checking the consistency and completeness among different requirements. The involvement of stakeholders is helpful to enhance the quality of both requirements and information systems. At the same time, all requirements would be documented in a standard format and be attributed to two categories, including functional and non-functional.

Liu and Li (2015) interpret the procedure of requirement engineering through the lens of semiotic triangle (Figure 2-18). The stage of requirement specification is to collect the description from different stakeholders that reflect their requirements of the developing information system. Then, the information will be processed, analysed and documented in a certain format. Eventually, they will be presented in a sense-making way to show the actual requirements of information system to the system designers.

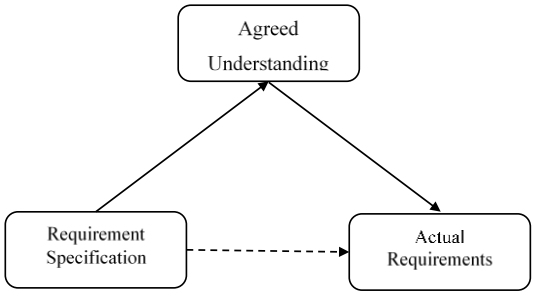


Figure 2-18 Semiotic triangle in requirement engineering (Liu and Li, 2015)

However, Liu and Li (2015) also mention some challenges for people to sufficiently understand the requirements. Firstly, insufficient stakeholder involvement might weaken the efficiency of requirement

engineering. Based on the traditional methods of requirement engineering, such as interview and questionnaire, it would be very costly to capture the requirements from a wide range of stakeholders. Secondly, since the improper design of the process, stakeholder requirements cannot be presented in a sense-making format, so employees in charities are unable to fit them with suitable visualisation methods. Huzooree and Ramdoo (2015) conducts an empirical research in 100 software development companies, in order to obstacle weakening the performance of requirement engineering. 40 per cent of feedbacks show that the lack of stakeholder involvement causes the misalignment between deliverables and requirements. More than 60 per cent of interviewees express that more effort should be put in requirement definition and requirement maintenance, in order to ensure the user's requirement to be understood by the system designers or to fit into the data input interfaces.

In the context of visualisation development, the management of users' requirements is one of dominant challenges (Brodlie, Allendes Osorio and Lopes, 2012; Osimo and Mureddu, 2015; Sarikaya, Gleicher and Szafir, 2018). The requirements tend to be diverse and based on different roles, positions, purposes and contextual pressures, which require the visualisation development as well as the interface to be flexible for adapting into the users' demands. The requirements might also be further developed while iteratively observing visual representations, which requires developers and analysts to update the requirement documentation and address them in the visualisation development. Due to the different background and knowledge between users and developers, without an agreed structured, the inconsistent understanding of information demands might undermine the performance and efficacy of visualisation.

2.3.4 Norms and Knowledge Representation

Knowledge can be simply defined as a belief that a person holds with his or her rational thinking (Davis, Shrobe and Szolovits, 1993). It is more than just encoding the objects and events which happened in reality, but influencing and even disciplining the interactions with the world (Sowa, 2000). Additionally, it can be understood as a congregation and systematic summary of data and information, from which new information derives (Meyer, 2013).

Knowledge representation also plays an important role on computer intelligence, which offer a wide range of approaches sharing information among different intelligent agents. Ryle (1949) categorise knowledge into two typologies in term of perceiving approaches, such as declarative and procedural (cited by Liu and Li, 2015). Declarative knowledge is oriented by theory, mainly focusing on concepts and the relationship among different concepts. Procedural knowledge is directed by practice, related to norms instructing the specific actions. Based on the depth of understanding, Nonaka and Takeuchi (1995) divide knowledge to two types: explicit knowledge and tactic knowledge. Explicit knowledge refers to the meanings directly reflected on words. On the contrary, tactic knowledge refers to the

speaker's intentions and social indications behind the simple verb description, which requires readers to have extra capability to articulate or explain the information.

For the purpose of helping people identify and understand tactic knowledge, Chandrasegaran et al. (2013) propose allowing tactic knowledge to be more explicit through utilising information documentation which can be regarded as a type of knowledge representation. To be specific, four methods have been built into their research, including storytelling, role-play in a certain scenario, role-shadowing and observation.

Sowa (2000) views knowledge representation as a subject across the boundary among multiple disciplines and domains, including logics, ontology and computation. Logics offers the method and process of reasoning and inferencing; ontology attributes the tokens and symbols into different specific domains; and computation plays the role of enabler to build knowledge representation in the reality. Liu and Li (2015) provide five methodologies, logic approach, semantic network, framework, norm-centric process and conceptual graphic, for the purpose of articulating the organisational culture and norms influencing behaviours and communication. In this research, norms will be applied as a knowledge representation to lubricate the communication of tactic knowledge, such as prior knowledge, demands, purposes and contextual pressures. In addition, Davis, Shrobe and Szolovits, (1993) pinpoint that norm can be utilised as a carrier to signifying knowledge with different roles and different functions (Table 2-4).

Table 2-4 Five roles of norms as knowledge representation (adapted from Davis, Shrobe and Szolovits, 1993*)*

Roles	Functions
A fundamentally surrogate	Physical objects, events and relationships that cannot be stored directly in a computer are represented by symbols and serve as surrogates for external objects.
A set of ontological commitment	For a database or knowledge base, ontology determines the categories of things that exist or may exist in an application domain.
A fragmentary theory of intelligent reasoning	It enables the reasoning process to be explicit behind a certain phenomenon, including knowing what and knowing why.
A medium for pragmatically efficient computation	It facilitates the pragmatic communication among different roles, where the speakers' intentions can be explicitly expressed and delivered.
A medium of human expression	It bridges the communication gap among stakeholders with different domain knowledge e.g. business users and IT engineers.

Referring to Wright (1977), norms are often referred as "standard" and "rule" for being taken as references for human behaviours and demands and enabling automated system s to perform the corresponding functions to fulfil the demands. The norm specification includes context (circumstance where the requirement is raised), condition (trigger for fulfilling the requirement), agent (people who takes actions), deontic operator (permission or prohibition or obligation) and action (specific actions

for fulfilling the demands). Liu (2000) suggests 5 categories of norms for governing human behaviours (Table 2-5).

Table 2-5 Five types of norms with explanation in IDV development context

Norms	Explanation (Liu, 2000)	Explanation in the context of IDV development
Perceptual norms	Associate with how people perceive signs from the environment via their sense e.g. colours and shapes.	Help users perceive the sign (visual representations) e.g. charts, layouts and colour codes.
Cognitive norms	Associate with how people understand the perceived signs with their prior knowledge.	Enable users to incorporate knowledge and experience for interpretation e.g. data requirements and data modelling.
Evaluative norms	Explain the reason why there is a certain values, beliefs and objectives.	Support users to discover reasons causing the observed data patterns and enable them to testify the causality among different data objects.
Behavioural norms	Govern people's behaviours within the regular patterns.	Govern user behaviour during the interaction e.g. annotation for further details.
Denotative norms	Direct the selection of signs based on the context.	Direct the selection and organisation of signs for signifying depending on the context.

In this research, the framework of abductive process will be further enhanced with the support of organisational semiotics, where the interactive functions will facilitate perception of semantic meaning, collection of users' intentions and involvement of social protocol. For the semantic level, interactive functions empower readers to address the ad-hoc information requests and experts to contribute their knowledge. For the pragmatic level, the abductive process, especially conversion loop, helps users to address their intentions, and enables interactive functions and authors to react with different visual representations. For the social level, the social norms can be integrated into data visualisation design, so that the logic and sequence of visual representations can follow the protocol derived from social context.

2.4 Abductive Process: Analytic Guidelines for Sensemaking

2.4.1 Abductive Reasoning Process in the Context of Visualisation

Data visualisation contains a logical reasoning process to signify or create knowledge (Moriarty, 1996). Thus, it requires interaction and a purpose-driven process. The mainstream reasoning paradigms includes induction, deduction and abduction (Ho, 1994). Compared with the other two approaches of induction and deduction, abductive reasoning incorporates prior knowledge with realistic observation, and encourages users to establish a new hypothesis or conclusion which can be justified in the following deductive reasoning process. On the scope of data visualisation, users should be allowed to address complexity of dataset by using an interactive filter and express their ad-hoc information requests by interactive setting mechanism. However, as suggested by Liu and Li (2015), the design of interactive function can follow the abductive process, where users' prior knowledge can be integrated, demands can be explicated, intentions can be captured, and social norms can be followed.

The term of "abduction" was proposed in the 14th century, and then adapted in the Peircean logical system where abduction guides people to interpret signs with the incorporation of their prior knowledge and then figure out a new hypothesis or proposition for further justification (Reichertz, 2007). For the other two dominant logical reasoning methods, deduction generates a conclusion based on an observed fact with integrating axiom, which helps people figure out a conclusion. Induction, as a process of finding a general rule, guides people to extract a universal principle based on prior knowledge and observation.

As suggested by Liu (2000), it enables the discovery of new theory and knowledge, which can spark the following inductive or deductive process. Abductive process starts from the prior knowledge or theoretical proposition, and then refine the prior knowledge or build new knowledge through making sense of signs in the observation.

The logical form of Peircean abduction can be presented as follows (adapted from Ho, 1994):

1. An unexpected phenomenon C has been observed (Observation)
2. If A existed, C would occur (Matching with prior knowledge)
3. Thus, a new hypothesis/proposition comes out: A might exist (New Hypothesis/Proposition)
4. The following action will continue the observation on the existence of A (Validation – Inductive Process)

March (1976) further develops another form of abduction reasoning in the context of design, which is referred as "productive inference". It is based on statement from Peirce that abduction is the only logical approach to generate new ideas, in comparison with induction which determines a value and deduction which examines and evolve hypotheses. Different from the sole focus on abduction, March (1976) acknowledges the integration of inductive and deductive elements into the abductive approach in design, by pointing out that based on the ideas created by abduction, deduction can predict the trends and induction can evaluate in details. Specifically, March's form of abduction consists of the following three main tasks and they will be iteratively implemented in the design process (e.g. PDIPDI…).

(1) Production (P) for creating a novel composition;

(2) Deduction (D) for predicting the performance and characteristics;

(3) Induction (I) for accumulating habitual notions for establishing a general understanding.

Roozenburg and Eekels (1995) further categories the March's form of abduction to two types of synthetic processes. The first one is explanatory abduction process where abduction is integrated with deduction for finding and refining the plausible explanation from one particular scenario to another. The second one is innovative abduction process where abduction is integrated with induction for iteratively discover and summarise the understanding generated from observation. It helps continuously developing the understanding of general rules.

Further developed from the Peircean Abduction, Thagard (2007) and Kovács and Spens (2005) propose the abductive process diagrams. Kovács and Spens (2005) describe the abductive process in theoretical and empirical worlds (Figure 2-19). In the theoretical world, humans can compare their observation with prior understanding; in the empirical world, humans can obtain information by interacting with sign and validate the hypothesis/proposition in the following practice. The overall process includes five steps:

0. (Preliminary stage) Prepare the prior knowledge in the theoretical world
1. Conduct real life observation and deviate the information with a certain predefined purpose
2. Match the observation with prior knowledge in the theoretical world
3. Suggest a new hypothesis/proposition (might go back to the observation for finding some materials, which is called conversion loop)
4. Apply the final conclusion in the empirical world, which might influence the following behaviour

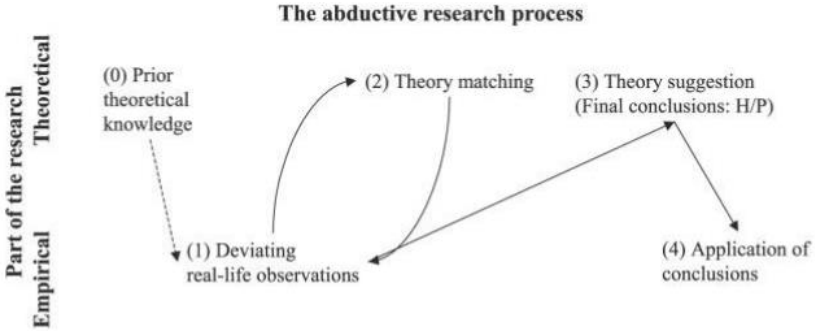


Figure 2-19 Abductive research process (Kovács and Spens, 2005)

Thagard's abductive reasoning process focuses more on phonology in empirical research (Thagard, 2007). At the end of this process, a psychological justification is set for knowing if the information obtained from observation can satisfy the readers' psychological demands (called "Satisfaction"). It consists of five stages (Figure 2-20):

1. Observe a surprising phenomenon (or puzzlement)
2. Search for explanation with prior knowledge
3. Generate plausible hypothesis/proposition
4. Validate the acceptance in empirical research
5. End with pleasure/satisfaction

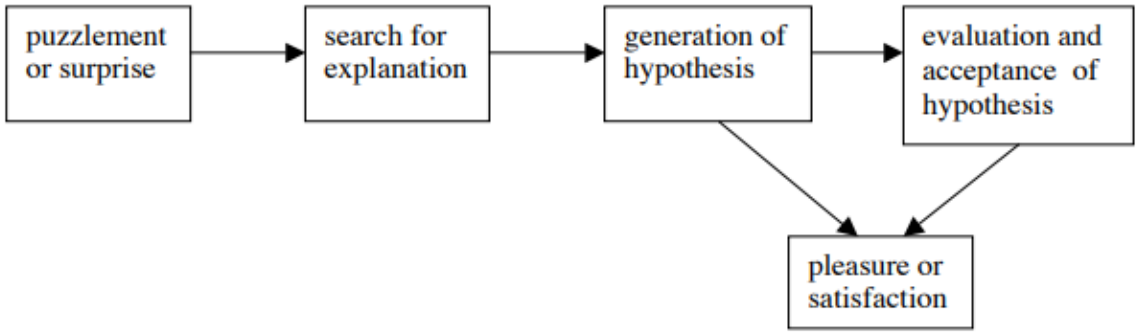


Figure 2-20 Abductive reasoning process (Thagard, 2007)

The application of abductive reasoning process has been suggested by previous research to analyse the process of data visualisation. Peircean Semiosis demonstrates the basic triangular framework of abductive process but does not reveal the specific steps of "interpretant" which associates sign and object. Based on the models from Thagard (2007) and Kovács and Spens (2005), they reveal the main steps of abductive process consisting of perception, cognition and convention. However, they have not addressed the methodology of taking semantic, pragmatic and social factors.

In this research, the abductive process proposed by Kovács and Spens (2005) will be mainly explored in the context of IDV development. Firstly, it incorporates the input of prior knowledge from the readers for guiding the initial design IDV. Different from Thagard (2007) which starts the abduction process of witnessing a puzzle, Kovács and Spens (2005) highlights the readers can engage in the IDV with their prior knowledge, compare them with their observation, and identify the differences (gaps). Secondly, Kovács and Spens (2005) also points out the importance of cognitive loop where readers can continuously review and interact with IDV artefact. Via incorporating data inputs, adjusting parameters and visual variables, readers can address their ad-hoc information demands and further develop their understanding towards the observed phenomenon. Although Thargard (2007) pinpoints the readers' feeling of "pleasure and satisfaction", it neglects that main purpose of entering in recognition loop is to acquire further information and develop new knowledge. Therefore, inspired by Kovács and Spens (2005), the process of recognition loop will be adapted into the discovery of the process of interactive function development. In addition, March (1976) will be incorporated into this research as its thoughts

of productive inference extends the abduction process from the focus on IDV artefact development to its influences to the readers' following behaviours. It encourages the researchers to discover how interaction with IDV artefact can impact readers understandings as well as their decision-making.

2.4.2 Sense-making Process in Data Visualisation

Sensemaking refers to how an individual interprets a phenomenon and then configures the actions to respond to it (Snowden, 2005). It contains two parts, including the obtaining of information from observation and then acting based on the obtained information. Dervin (1983) develops the concept of sensemaking as a gap-bridging metaphor. Sensemaking is launched when people identify a gap, such as an unclear and confusing phenomenon, which prevents further movement (referring to the understanding of the fact). Then, for the purpose of bridging the gap, they might try to incorporate different information sources to develop their understanding of the corresponding phenomenon. Finally, based on the refined understanding, they might configure a solution (referred as a bridge) to overcome the gaps and move forward. Dervin and Foreman-Wernet (2012) points to the sensemaking depending on the context, which echoes the OS theory that communication needs to fit into the given social context. They further point to four questions for guiding sensemaking: what is situation? (context); what confuses you? (the gap); what solution have you configured? (the bridge); and how has it helped? (the outcome). Weick (1995) further develops the concept of sensemaking by addressing the following characteristics: 1) sensemaking carries a social attribute: people interact with others and are also influenced by others during the sensemaking process; 2) sensemaking is an ongoing process where understanding is constantly changing with incremental observations; 3) sensemaking is driven by plausibility instead of accuracy: people iteratively observe the phenomenon with a focus on plausibility and sufficiency and cease the observation once an acceptable explanation is found. Russell *et al.* (1993) further define sensemaking as a task-specific process where people can seek representation to understood data as well as encode data to representation for communication purposes. Pirolli and Card (2005) have constructed a process model which highlights the interconnection between data and knowledge. In the context of visualisation, sensemaking process enables users to explore new knowledge via making sense of datasets through visual approaches. It also emphasises the iterative features of the visualisation process, including foraging loop (for knowledge to data) and sensemaking loop (from data to knowledge). The sensemaking process is described in five steps: searching and filtering, reading and extracting, schematising, case building, and storytelling (Figure 2-21).

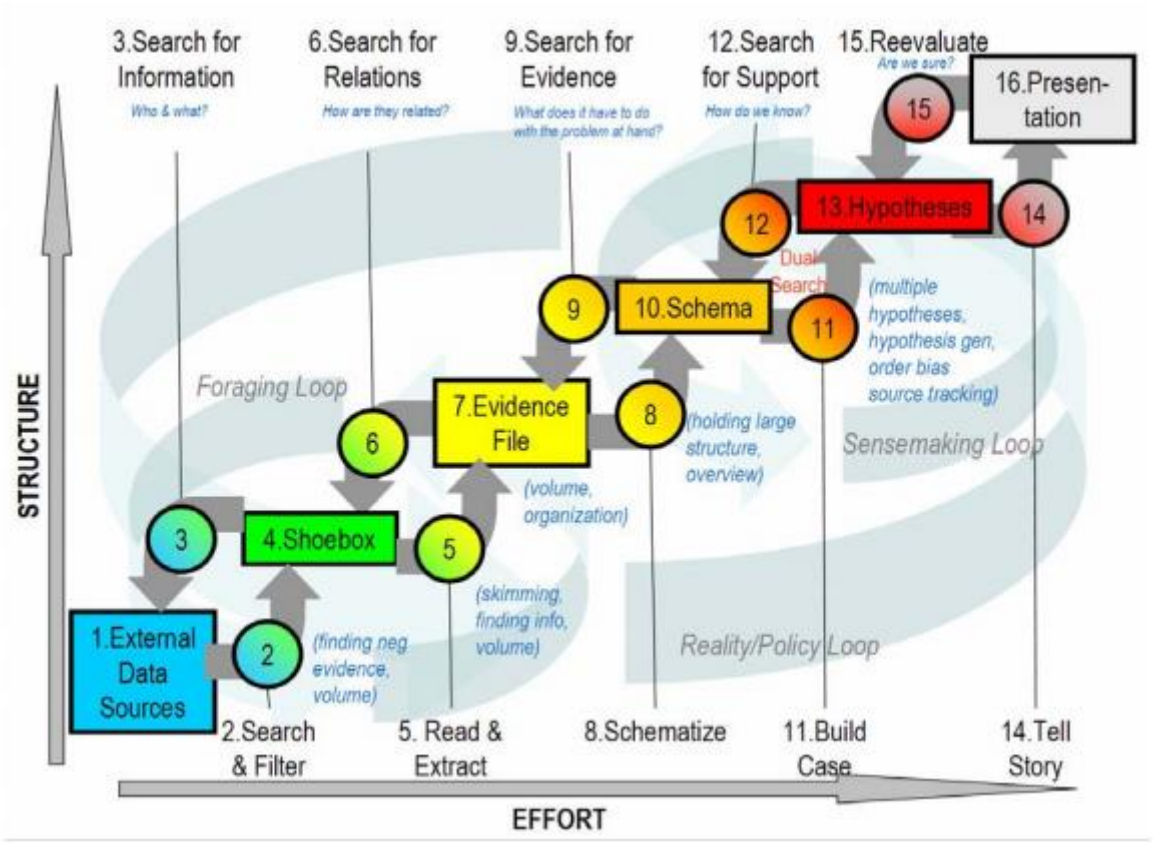


Figure 2-21 Notional model of sensemaking process and loops (Pirolli and Card, 2005a)

Klein *et al.* (2007) further develop the sensemaking process model by highlighting the role of data and frame during the sensemaking process. Data refers to the evidence that users are searching for and perceiving to extract information. Frame refers to the mental model which users utilise to interpret data and construct knowledge. They portray seven activities of data-frame interaction: connecting data and frame, elaborating frame, questioning frame, preserving frame, comparing frame, refining frame, and seeking a new frame. The data-interaction interaction echoes the process of abductive reasoning where users bring their prior knowledge to observation and refine/construct new knowledge via continuous observation and interpretation. Therefore, different from the prior studies which focus on data and knowledge, Klein *et al.* (2007) incorporate the role of mental frame where users' information demands, interpretation purposes and contextual influence shape their approaches of making sense of datasets.

In the context of IDV development, the outcomes of reviewed research about sensemaking can be further associated with the key concepts of OS theories and abductive reasoning process, which can further help with establish a framework portraying the process and mechanisms of IDV development (Table 2-6).

Table 2-6 OS theories and abductive reasoning in the context of sensemaking

Key concepts from OS theories and abductive reasoning process	Highlighted outcomes from the prior studies of sensemaking

IDV needs to cater to the information demands of users (semantic level on the semiotic ladder)	Gap-Bridging metaphor for searching information and resolving puzzles (Dervin and Foreman-Wernet, 2012)
IDV needs to align with users' purpose of interpretation (pragmatic level on semiotic ladder)	Sensemaking is a task-specific process (Russell *et al.*, 1993)
IDV needs to fit the context of sensemaking	Social attributes of sensemaking (Weick, 1995)
IDV can serve knowledge exploration and action configuration based on findings	Sensemaking process of constructing the interconnection between data and knowledge (Pirolli and Card, 2005a)
IDV can incorporate the abductive reasoning process where the iterative process allows users to continuously address and refine their requirements	Data and framework interaction and iterative process of constructing/refining frames based on data (Klein *et al.*, 2007)
IDV development can be norm-centric for specifying the information, purposes and the context of sensemaking	Mental frame can be understood as an integration of information demands, interpretation purposes and the contextual impacts of sensemaking. (Klein *et al.*, 2007)

2.4.3 Prior Frameworks of Data Visualisation

Due to information-overloading and the increasing complexity of datasets, static data visualisation can no longer fulfil the various demands from different users (Chen and Rabhi, 2016). The research focus has gradually shifted to the function of interaction, where users can address their specific demands and preferences for displaying datasets by interacting with the interface of data visualisation (Goguen and Harrell, 2003; Segel and Heer, 2010; Liu and Tan, 2015). It moves the research to analyse data visualisation in the paradigm of the social-technique concept, where visualisation is context-dependent, purpose-driven, interactive and serves knowledge exploration (Manovich, 2011; Vickers, Faith and Rossiter, 2013). Based on the literature review, there are different conceptual frameworks from prior studies which depict concepts, process and iterative feature of visualisation with different terms and different perspectives (Table 2-7).

Table 2-7 Relevant studies of visualisation concepts, process and iterative features

Key Themes for Review	Key Features or Concepts
Concepts and key features of visualisation	Reasoning and communication process (Spence, 2001); Information graphics (infographics) (Tufte, 2001); Story narrative process (interoperation between readers and designers) (Segel and Heer, 2010; Man, 2011); Information visualisation (interlocks with datasets, interpretation and context) (Ware, 2004); Knowledge visualisation (Paul, 2001; Meyer, 2013); Digital visualisation (compound concept of data, information and knowledge; norm-centric process) (Chen *et al.*, 2009; Liu and Tan, 2015)
Portrait of Data Visualisation Process	visualisation process (Ware, 2004; Chen *et al.*, 2009; Liu, 2014), visual analytic process (Keim, Andrienko, J. Fekete, *et al.*, 2008; Edge *et al.*, 2018), visualisation & sense-making process (Endert, Fiaux and North, 2012; Nguyen *et al.*, 2016), visual analytic provenance (Buneman, Khanna and Tan, 2000; Gualtieri *et al.*, 2001; Nguyen *et al.*, 2016). In addition, there are some shared components, such as visual mapping (Chi and Card, 1999; Keim, Andrienko, J. Fekete, *et al.*, 2008), view generation (Card,

	Mackinlay and Shneiderman, 1999; Van Wijk, 2005) and interaction/iteration/loop (Ware, 2004; Chen *et al.*, 2009; Kodagoda *et al.*, 2013; Liu and Tan, 2015),
Iteration and reasoning process	visual analytic pipeline (Programming, 2007; Featherstone and Poel, 2014; Chen and Golan, 2016), visualisation & feedback loops (Ware, 2012; Kastens, 2017), and visualisation & insight provenance (Wang *et al.*, 2016), norm-centric process and interactivity (Liu and Tan, 2015), Inductive and deductive reasoning in visual analytics (Arrighi and Ferrario, 2005; Pirolli and Card, 2005b; Patterson *et al.*, 2014; Lee *et al.*, 2016; Nguyen *et al.*, 2016)

The selected milestones of visualisation frameworks are reviewed in this sub-chapter, in order to inspire the construction of IDV development framework in this research. It includes Wijk (2005) and Munzner (2009) who portray this generic process of visualisation development, (Segel and Heer, 2010) who balance author-driven and reader-drive process, Ahn and Brusilovsky's (2009) who constructs an adaptive visualisation process with features of adapting to the sensemaking context, Vickers, Faith and Rossiter (2013) who describes the visualisation process based on Peircean semiosis, and Liu and Tan (2015) who demonstrate visualisation as an abductive and norm-based process.

Wijk (2005) proposes a generic visualisation model, derived from the reference model of visualisation Chi and Riedl (1998). Other than portraying the process of generating visualisation based on datasets, it puts the emphasis on the role of knowledge. In the visualisation process (Figure 2-22), knowledge can be accumulated via P-K-P (continuous observation). Interaction (V-P-K-E-S-V) allows users to iteratively post a new enquiry of visualising data by expressing the specification on visualisation, such as focusing/highlighting, filtering and selecting. Wijk (2005) further claims that users perceive information from visualisation and transfer them to knowledge for guiding the following actions.

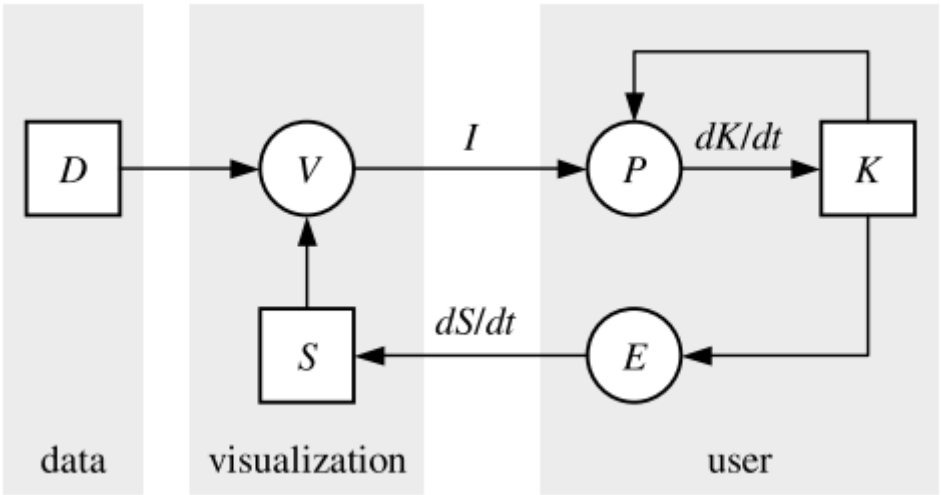


Figure 2-22 An simplified model of visualisation development process (Wijk, 2005)

The iterative nature of visualisation can be observed since users would adjust their specification of visualisation to acquire more knowledge. It has been further developed by the nested model from Munzner (2009), where the visualisation process starts with users' knowledge of domain problem characterisation, and then lead to the further designing activities of data/operation, visual encoding/interactivity and algorithm. The development activities can help build up the knowledge of domain problems, which constitutes a refinement process.

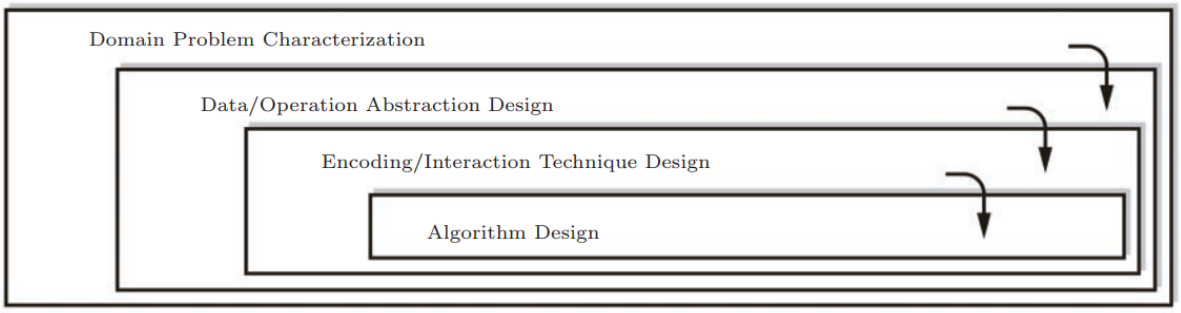


Figure 2-23 Nested model of visualization creation process (Munzner, 2009)

Segel and Heer (2010) focuses on the collaboration between author and reader during the process of visualisation. Their work discusses the balance between two philosophical paradigms for visual representative design, which are author-driven and reader-driven:

- Author-driven paradigm: the visual displays and representations are static and fixed, which leaves no freedom for readers to explore the datasets. It includes the feature of linear process, heavy messaging and little interactive functions.
- Reader-driven paradigm: an open platform for visually displaying data will be provided to readers, which requires readers to discover the patterns from datasets based on their own knowledge and understanding. It includes the non-predefined order, little messaging and free interactive function.

Three suggested models are offered in this research, which includes a martini glass model for narrative visualization, interactive slideshows for story line and drill-down story for interactive functions. First, the Martini Glass visualisation structure combines both author-driven and reader-driven paradigms during the visualisation. It starts with an author-driven approach, like an induction of visualisation, where visual representations were developed based on predefined questions. The author can use written article or annotation attached with visualisation in order to introduce the content, purposes and functions of visualisation to readers. Once the authors' induction is completed, the reader possesses a large degree of freedom to explore the datasets via the interactive functions embedded in the visualisation. It is a common practice in the interactive visualisation which it remains the author's induction to offer an initial guide of visualisation and provide an open opportunity for readers to conduct an exploratory analysis of datasets. Second, the interactive slideshow structure adapts a traditional slideshow format

with an incorporation of interactive functions on each slide. The author would predefine the order (storyline) of visual representations, which enable author to guide readers to "walk" through all data dimensions and even manipulate readers' observation step-by-step. Readers are only allowed to move forward or backward among slides and explore some particular points of the presentation. The interactive slideshow structure is mostly led by authors to navigate the observation of readers with a predefined focus and storyline. Third, the Drill-down story structure mostly relies on reader-driven approach, where users can dictate the visual representations and storyline. It starts with a presentation of a general theme and then users can select a particular theme to reveal additional details. The role of author is mainly for supporting the visualisation development, such as modelling the appropriate data and selecting a suitable visual representation and interactivity based on readers' enquiries. In this research, further developing the research of Segel and Heer (2010), three visualisation models are employed in the different stage of IDV development process. Echoing the abductive reasoning process, Martini Glass Structure can be utilised at the initial stage to overview the dataset; Drill-down story structure can be used at the iterative part (development cycle) to enable users to explore the dataset; Interactive slideshow can be applied in the final stage to wrap up and share the knowledge with different stakeholders.

In addition, suggested by Ahn and Brusilovsky (2009), the concept of adaptive visualisation emphasises the adaption of interactive system in data visualisation. It enables the visual variables, structure, methods and components to adapt to the context where the users make sense of datasets. Ahn and Brusilovsky (2009) propose the Visual Information Browsing Environment (VIBE) model to address two main questions, such as "what to adapt" and "how to adapt". The question of "what to adapt" can be specified to the following four key points:

- Information adaption: selecting the right information for display
- Presentation adaption: displaying information in a correct way
- Interface adaption: designing an interface with the right functions
- Context adaption: presenting information in a correct scenario

Then, the question of "how to adapt" associates with the classification of visualisation adaptions, which can be described in four aspects:

- Visualisation method adaption: selecting and refining visualisation techniques
- Visual structure adaption: changing the layout of visual representations and altering the presentation methods for facilitating the exploratory analysis
- Adaptive annotation: changing visual elements to highlight the focal data patterns or associating extra textual information with the visualisation
- User model adaption: deriving user mental frame and amplifying the readers' cognition effect

The system view of the VIBE model is presented in (Figure 2-24). It highlights that visualisation is context-dependent, where users' query and mental model lead the development visualisation and the

observation which occurred in the "shoebox" can help update the user model by exploring new knowledge.

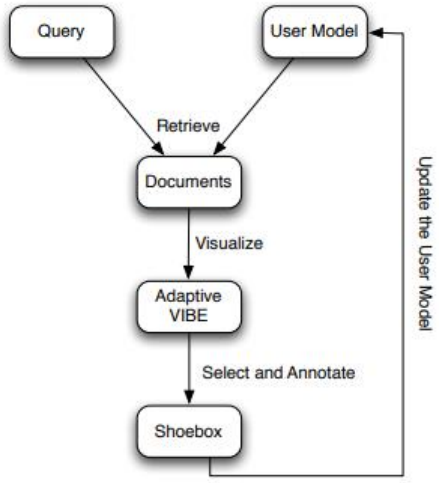


Figure 2-24 VIBE model (Ahn and Brusilovsky, 2009)

Vickers, Faith and Rossiter (2013) establishes a conceptual model of visualisation process based on category theory. It adapts Peircean semiosis to portray the relationship among different entities during the visualisation process, including data (object), representation (sign) and evocation (interpretant). The elaboration of the visualisation process (Figure 2-25), including entities and connections (morphisms) and with emphasis on four main entities: system (object or phenomenon in the real world), data (datasets measuring one or more aspects of a real world system), representation (visual representations to signifying data), and evocation (what representation signifies in the users' minds when reading representation; referring to a process of making sense of data). In addition, Vickers, Faith and Rossiter (2013) pinpoints eight objects consisting of the detail level of visualisation process, which are system, schema, data, layout, representation, questions, evocation and knowledge (Figure 2-26), which further inspires the sub-activities of IDV development in this research.

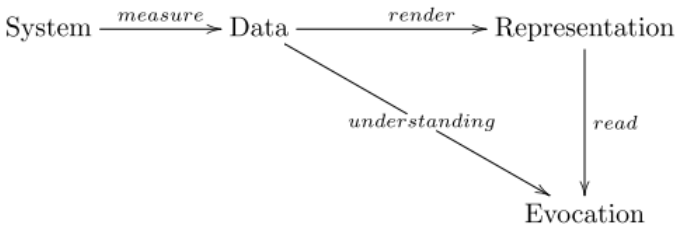


Figure 2-25 Visualisation process derived from Peircean Semiosis (Vickers, Faith and Rossiter, 2013)

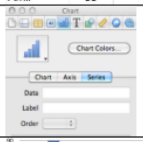
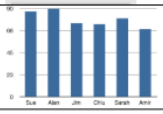
Category Object	Example
System	A cohort of students on a course
Schema	Student Grade ... ...
Data	Student Grade Sue 87 Alan 90 Jim 75 Chiu 74 Sarah 80 Amir 69
Layout	
Representation	
Questions	$best\_mark(\_)$ $average\_mark(\_)$
Evocation	$best\_mark(Alan)$ $average\_mark(> 70)$
Knowledge	"Alan performed the best", "Nobody failed", "The average mark was satisfactory"

Figure 2-26 Eight objects in the detailed level of visualisation process (Vickers, Faith and Rossiter, 2013)

Other than technical factors, based on the keynote speech delivered by Liu (2014) which describes data visualization as a process involving both technical and social factors, Liu and Tan (2015) further specify that the process consists of five components: data collection, transformation, mapping, displaying and interacting. It also specifies visualisation as an abductive process (Figure 2-27), where users can search for an explanation, generate a new hypothesis, examine a hypothesis and configure actions. Norm play an important role during the process for governing users' behaviours and specifying their requests. Particularly, the specification of a norm can help manage users' requirements from different aspects, such as information need specification (what is key information), purposes (what is key information for), context (when, where and how is information presented). Also, six norm categories help map the user requirements to the different activities of visualisation, which can lead the visualisation development and contribute to the alignment of visualisation development and user requirements.

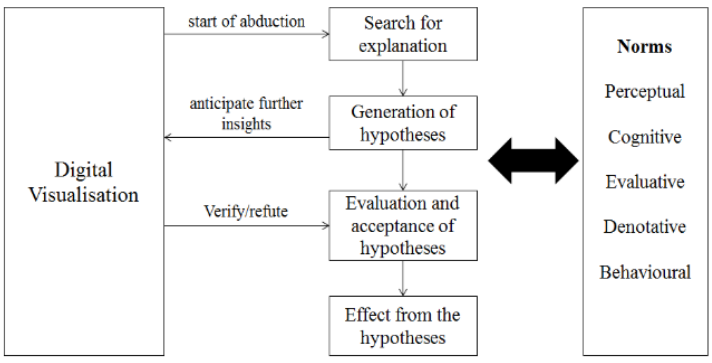


Figure 2-27 Visualisation as a process of abduction (Liu and Tan, 2015)

Based on the review above, the following research gaps can be identified. 1) Although there is well-grounded research portraying the process of sense-making in the context of visualisation, the main focus remains on the readers or author, instead of the collaboration between readers and authors as well as the input of expert knowledge. 2) Although there is well-defined category of visualisation entities, objects and activities, there are inadequate efforts made to map them to different stages of data visualisation as well as to users' demands and purposes. 3) Although the users' engagement (especially for knowledge input and exploration) has been highlighted in the prior studies, there are not enough detailed guidelines and mechanisms to implement during the process of data visualisation development. Therefore, inspired by the reviewed framework, three preliminary theoretical propositions will be examined and further developed based on the observation and user feedback in the case studies, for the purpose of leading the construction of new IDV development framework (Table 2-8).

Table 2-8 Preliminary theoretical propositions in this research

No.	Preliminary theoretical propositions for guiding the construction of IDV development framework	Relevant references
Proposition 1	IDV development is a norm-centric process	(Ahn and Brusilovsky, 2009; Liu and Tan, 2015)
Proposition 2	Abductive reasoning process is embedded in IDV development	(Moriarty, 1996; Van Wijk, 2005; Munzner, 2009)
Proposition 3	IDV development enables visualisation to serve knowledge exploration	(Pirolli and Card, 2005b; Vickers *et al.*, 2012)

2.5 Key Assumptions for Exiting Research

Based on the review and discussion in this chapter, the following three assumptions can be made to further guide this research. The IDV development is assumed to strike three balances: 1) process and artefact; 2) interpretation and data; 3) subjectivity and objectivity.

2.5.1 Process and Artefact

Visualisation can be defined as an artefact, like a tool or software, of making graphs to represent datasets and communicate the dominant data patterns. The users' requirements and evaluation of visualisation performance also concentrates on the quality, capacity and efficacy of visualisation artefacts. However, without a well-developed and well-managed process of engaging users and specifying their demands, some key issues, such as misinterpretation of meanings, ignorance of users' intentions and unfitness of social context, hinder the effectiveness and efficiency of data visualisation. Therefore, instead of solely focusing on the designing the data representation (the result), the research focus has gradually moved to the process of visualising data. The main question of data visualisation should be modified from how to make an image to how to visualise data with an orientation of users' demands. Therefore, the IDV

development needs to balance its focus on both process of continuously acquiring and addressing users' requirement and the artefact fulfilling users' demands.

2.5.2 Interpretation and Data

Influenced by data-oriented decision-making system, people increasingly believe in letting data tell the story. Without sufficient support of interpretation, data itself cannot generically reveal the meaning and cater to readers' information demands (Segel and Heer, 2010). Thus, since data is the raw material of information, interpretation will take place to bridge the gap between data and information – help readers extract information from data with sufficient consideration of readers' demands, intentions and contextual information. Norms play an important role in configuring a shared understanding of the following three themes: users' information demands related to semantic meanings, an effective solution for capturing and responding to readers' intentions and purposes, and adequate awareness of sense-making context. Thus, other than collecting data as raw materials for visualisation, uses' information needs, purposes and context for interpretation are just as important for IDV development.

2.5.3 Subjectivity and Objectivity

Data visualisation is socio-technical process where it is necessary to strike a balance between subjectivity and objectivity. In other words, based on the objectivity contained in the dataset, the subjective factors carried by readers and contained in the organisational environment should be addressed in the data visualisation as well. Visualisation not only reveals the patterns of datasets, it also facilitates the users' knowledge exploration. Therefore, visualisation can often be portrayed as an iterative process where users obtain and refine their knowledge for guiding the following actions while interacting with visualisation interfaces. (Chen *et al.*, 2009; Chen, Floridi and Borgo, 2013). Therefore, as regards visualisation development, it is assumed to strike a balance between identifying and revealing the patterns of datasets and exploring new knowledge based on visualisation.

2.6 Summary

This chapter has reviewed the key literature related to this research. The reviewed literature includes the basic definitions and important phases of data visualisation development, visualisation systems, principles and components of data visualisation and semiotics as a theoretical foundation of visualisation development. The definition of data visualisation demonstrates various research focuses of data visualisation, indicating that data visualisation development needs to strike a balance between process of eliciting and managing users' requirements as well as an artefact of fulfilling users' demands. The development of data visualisation reveals trends of IDV development, where more focuses are moving to the integration of visualisation, analysis and users. It indicates visualisation needs to adapt to users' demands and facilitate their exploration of dataset (analysis and interpretation), which constitutes a balance between data and interpretation. The discussion visualisation systems, principles

and components offer a wide range of guidelines to map users' requirements to the specification of visualisation development, such as selection of chart types, forms and style. Organisation semiotics offers a set of useful methods, include semiosis, semiotic ladder, requirement engineering process and norms for the purpose of pinpointing the socio-technical characteristics of IDV development. They can help with maintaining the balance between objectivity and subjectivity.

3. Research Methodology

This chapter describes the methodology utilised in this research, including an in-depth discussion of dominant research paradigms in the study of information systems, followed by a discussion of dominant research strategies. The research paradigm in the context of this research, such as design science as well as the research strategies such as the case study, is discussed in this chapter. In addition, the abductive research approach is also discussed for the purpose of justifying its contributions and fitness to this research. By the end of chapter, the adopted research paradigm, strategies, approaches and methods are illustrated in a detailed manner. The discussion of research methodology adapts the basic guidelines of research onion from Saunders, Lewis and Thornhill (2015), which consists of paradigms, methodologies, approaches, strategies and then in-depth research design.

3.1 Research Paradigms

Referring to the definition of research paradigm, it covers a set of shared assumptions, concepts, value and practices, which support scientific inquiry for research purposes (Johnson and Christensen, 2016). It offers diverse views of defining what research is and how it can be associated with existing knowledge and prior studies. To be specific, a research paradigm can be understood as a collect of guideline to help researchers developing theoretical proposition and implementing the research in an effective approach. Referring to Kuhn (1962), research paradigms help with defining a research based on the following questions:

- What phenomenon will be investigated?
- What questions will be asked related to the phenomenon?
- How will the questions be addressed?
- How will the results be interpreted?

Therefore, in this research, research paradigm will be used as a general guideline for identifying and presenting acceptable answers for the research questions.

Paradigm, as an approach to understand the reality and address the complexity in the real world, is guided by the following three assumptions: ontology, epistemology and methodology (Chen and Hirschheim, 2004). The ontological assumption forms the basic opinion about the nature of reality, including what it is and how it works. It contains two perspectives of realities, including objectivity where no human interference is involved in reality, and subjectivity where reality is influenced and even shaped by the human actions and opinions. The epistemological assumption focuses on the nature of knowledge, the process where knowledge can be inquired and approaches of validating knowledge. The methodological assumption is associated with the specific approach by which an inquirer can find knowledge.

Other than the philosophical assumptions, the research paradigm also incorporates different paradigmatic views. There are four views often utilised in the research of information systems, including positivism, interpretivism, critical realism.

3.1.1 Positivism

Positivism sticks to the basic assumptions of objective reality, aiming at discovering law-like causation among different facts by conducting empirical research, in order to construct predictive power. To be specific, positivists believe that there is a single and concrete objective reality which exists (Saunders, Lewis and Thornhill, 2015). Under positivism paradigm, the phenomena are usually investigated with predefined instruments due to the brief of a static causal relationship which exists in reality. The positivists therefore intend to examine the existing theories as hypothesises with quantitative methods and measurable variables for the purposes of establishing a generalisable and predictive understanding (Orlikowski and Baroudi, 1991). For epistemology, positivism states that investigation of observable and measurable facts can contribute to finding causal explanation and prediction of objective knowledge. For methodology, positivists often adapt the methods from natural science, deducing hypothesises and examining and predicting phenomena with a highly structured method.

3.1.2 Interpretivism

Interpretivism assumes socially constructed reality, where a human's interpretation can be influenced by their intentions as well as their social environment. Interpretivism aims at interpreting actors' behaviours with the reference of their subjective frame and influences of their surrounding social environment (Walsham, 2006). Interpretivism often shifts the focus from the observable and measure factors to the subjective meaning assigned to the factors and interpret the potential rationales behind them. Contradictory to positivism, interpretivism does not solely depend on prior knowledge or existing knowledge associated to the phenomenon, but upon new interpretations and knowledge. Additionally, interpretivists often look for an in-depth understanding of a specific phenomenon, instead of inferring to a generalisable rule (Orlikowski and Baroudi, 1991). Therefore, for ontology, interpretivists generally assume that reality is shaped and constructed based on the subjective understanding of human. For epistemology, interpretivism states that the nature of knowledge is subjectively established during the process of social interaction and participation between researchers and participants. For methodology, interpretivism can align with inductive or abductive approaches, which allows for finding new knowledge without being constrained by existing theories. It also often takes social interaction into account, for the purpose of collecting raw data related to the targeted phenomenon with sufficient awareness of its social context.

3.1.3 Critical Realism

Critical realism assumes that reality is stratified based on the mechanisms and structures which produces all facts happened in the past. By applying abductive reasoning approach (also called retroduction), ever-deepening layers of reality will be keep being discovered by addressing the limitations of human understanding; this then enables researchers to configure the theoretical propositions which will account to the facts (Mingers, 2004). Since it recognises that the social world is constructed by multiple objects, forces, concepts and social structures, and human's knowledge inquiry will be directly and indirectly impacted by them, multiple research approaches will be allowed to be incorporated into this paradigm. Mingers and Willcocks (2014) demonstrates critical realism as a comprehensive philosophy to guide information system research and encourage it to be applied in the empirical studies. It accepts that the insufficient objectivity of human knowledge and the social theories must be evaluative, not descriptive, which motivates researchers to discover the deeper layers of objective reality. Critical realists believe that a certain amount of flexibility needs to be allowed for the human perception of a phenomenon, since there is a difference between the reality and perceived reality of a human (Mingers, Mutch and Willcocks, 2013). Therefore, this paradigm aims to look at explanation of social phenomena, instead of seeking for predictive capacities. It examines a series of key factors which might impact upon human's perception of reality, including context, mechanisms of perception and perceived outcomes, and recognises the constraints of human perception within cultural, political and natural environment. For ontology, similar to interpretivism, critical realism assumes that the reality is constructed and impacted socially via interaction between subjective perception and objective existence. For epistemology, critical realism assumes that environmental characteristics of society, culture politics and economy have a significant impact on the construction of social reality. For methodology, ethnographic and historical research approach will be utilised to support the analysis of socio-environmental and historical situation to uncover the long-term social restrictions impacting the perception of reality.

3.2 Research Methodologies

Research methodology refers to the general method to find answers for a research question. It includes two domain categories of methodology: qualitative and quantitative. The discussion will be explained from the perspectives of research paradigms, approaches and strategies.

3.2.1 Quantitative Methodology

The term "quantitative" refers to any methods of data collection and analysis which generate and incorporate numeric data (Saunders, Lewis and Thornhill, 2015). Quantitative methodology is, therefore, often associated with positivism, relying on objective measures of relationship with the aid of numeric and statistical analytic techniques (Duffy, 1985). For research approaches, the researches under quantitative methodologies also often adapt deductive research approach, to examine the hypothesises generated from existing theories with statistical tests. For research strategies, quantitative

methodology incorporates strategies such as questionnaires survey, experiment and mathematical modelling. Therefore, to some extent, the quantitative methodology is not suited to establishing an understanding of complex social phenomena with diverse causes and interpretations.

3.2.2 Qualitative Methodology

The term "qualitative" refers to any method of data collection and analysis which generates and uses non-numeric data (Carr, 1994; Creswell, 2014). Qualitative methodology is, therefore, often connected to interpretivism, which aims to understand the meaning that people associate with particular social phenomena. For the research approach, qualitative methodology often relates to inductive approach which generates new insights based on the data collected during investigation. It can also be utilised in the abductive research approach that enables research to iteratively examine and refine their hypothesises for the purpose of configuring a new understanding via continuously analysing the various types of data with little constraint from the predetermined models in the positivism (Howe, 1988). For research methodologies, it can also utilise the research strategies, such as case studies, action research and grounded theory.

The specific research techniques will be discussed in Table 3-1.

Table 3-1 Research Methodologies and Techniques

Research Methodologies	Research techniques	Description	References
Qualitative research	Interviews	A conversation with participants, oriented by researchers' specific needs of data. The specific types include structured, semi-structured and un-structured interview. It can also be conducted on an individual or group basis.	(Carr, 1994; Saunders, Lewis and Thornhill, 2015)
	Observation	Witnessing a specific phenomenon with a focus on a phenomenon as well as participants' relevant interpretation. It consists of the following actions: systematic viewing, recording, description, analysis and interpretation of observed phenomenon and participants' reactions. It includes participant observation and non-participant observation.	(Corbin and Strauss, 2014)
Quantitative research	Experiment	A set of tests to examine the validity and reliability of hypothesis with controlled conditions.	(Muijs, 2010)

	Survey	A deduction-oriented research technique to examine the existing relationship among different variables with structured and measurable instruments. By using questionnaire, a large number of samples can be collected, followed by statistical techniques which render the quantitative results generalised to the population.	(Neuman, 2014)

3.3 Research Approaches

The dominant research approaches include induction, deduction and abduction, which can be regarded as basic approaches of logical reasoning (Liu, 2000). Logical reasoning can be utilised to answer a research question via a developed process of reasoning, including the start point, process of generating answers and final outcomes of addressing the research question. The details of each approach will be discussed in this sub-section from the perspectives of research paradigms and theory development processes.

3.3.1 Deduction

The deductive research approach refers to the reasoning process, where researchers start with the review of existing theories, generate hypothesises based on the conclusions of prior theories, and examine them in different contexts (Liu, 2000; Kolko, 2010). Three key characteristics of deduction will be highlighted in the discussion. Firstly, it is often associated with positivism, which seeks to identify the causality between concepts and variables and generate a law-like conclusion for productive purposes. Thus, it would further adapt highly-structure methodology, like establishing a pre-determined model before data collection for specifying the precious conditions where the theory stands; data collection is appropriate. Secondly, all concepts in deductive research approach are required to be able to be operationalised. In other words, the concepts are often measurable quantitatively. Thirdly, the deductive approach is generalisable, since it adapts a rigidly developed method and procedure for carefully selecting samples under precious conditions and with a sufficient size.

3.3.2 Induction

Inductive research approach refers to the reasoning process where researchers start with collection of data related to a phenomenon via observation, discover patterns of data or the plausible explanations of the phenomenon, and finally construct a new theory in the form of conceptual framework. Different from deduction as a positivism-oriented approach focusing on cause-effect links, induction intends to

explain the causes behind a phenomenon with an understanding of the human interpretation toward the social world. It often echoes interpretivism (Liu, 2000; Kolko, 2010). Three key characteristics of induction will be highlighted in the discussion. Firstly, it can take the subjective elements, such as the way in which the participants interpret the social world, when explaining the possible reasons for a social phenomenon. Secondly, it allows researchers to adapt a flexible methodology, which is less structured compared with the one in deduction, to reveal the alternative explanation which is not initially expected from the research design. In this sense, it can unearth more potential explanation without the constraints of predetermined models. Thirdly, the inductive approach can be sufficiently aware of the impact of context where the observed phenomenon happens. It can therefore be more appropriate to qualitatively analyse a small size of samples with an in-depth understanding of contextual information, compared with a large sample size with a limited focus on a few predefined variables.

3.3.3 Abduction

The abductive research approach refers to the reasoning process where the researcher starts with data collection and exploration of phenomena, then identifies the key trends and pattern with potential explanation, and then generates a new theory or modifies an existing theory that researchers further examine with continuous engagement of additional data collection (Liu, 2000; Kolko, 2010). Therefore, Suddaby (2006) defines abduction as a scientific inquiry approach with a combination of two approaches, both induction and deduction, instead of either moving theory to data or moving data to theory. There are three dominant characteristics compared with other two approaches. Firstly, this is different from deduction which mainly examines the hypothesises from the prior theories, abduction grants researchers with opportunities to form and propose a new hypothesis during the observation, which can contribute to new ideas and knowledge. Secondly, different from induction which mainly relies on the movement from observation to theories, abduction highlights the iterative process of understanding which allows researchers to keep testing and refining the hypothesis or proposition during the observation until they find the best answer for the phenomenon. Thirdly, instead of focusing a specific context in induction or being constrained by the rigid predetermined models in deduction, it can incorporate both qualitative and qualitative methods to identify “surprising factors” or “puzzles” for the purpose of finding out the most appropriate explanation among alternatives.

All in all, induction refers to the research approach of establishing a set of new hypotheses during observation in a certain context. Deduction refers to the research approach of testing the hypotheses generated from the existing literature with a large scale of empirical data. Abduction refers to the research approach of forming and upgrading hypotheses and understanding via iterative observation of phenomena. The specific features of three approaches will be summarised in Table 3-2**.**

Table 3-2 Comparison among induction, deduction and abduction

Feature	Induction	Deduction	Abduction	Reference
Aim	Infer a general rule based on the observation of phenomenon in a specific context	Examine a general rule with a large scale of data input	Establish and refine the hypotheses or proposition to explain the observed facts	(Lopez, 2013)
Analysis pattern	From data to theory	From theory to data	From theory, to data, and to establish a new theory	(Ho, 1994)
Allowance of new knowledge	Yes	Confirm/reject the hypotheses from the existing theories	Yes	(Kovács and Spens, 2005)
Discovery mode	Data-oriented	Theory-oriented	Theory-informed	(Fischer *et al.*, 2012)

3.4 Research Strategies

3.4.1 Design Science

With regard to the different definitions of design science research, this can be understood as an essential approach to solve problems, where researchers can create and evaluate artefacts through developing individual and organisational capacity and knowledge, in order to offer a solution to a given problem (Gregor and Hevner, 2013). As one of fundamental methodologies in the information system research, design science aims to solve the recognised issues in an organisational context through creating and evaluating new artefacts, including models, methods and frameworks. It can help incorporate multiple stakeholders in a research context for collecting their input of experiences. Due to its identical contributions to the real practice, design science research has been widely applied in the research of informatics research.

As highlighted by Dorst (2011), abduction can be perceived as an important reasoning process to facilitate the development of solutions toward a complex problem. Further addressed by Walls, Widmeyer and El Sawy (1992) and Hevner *et al.* (2004), the nature of design science research contains the feature of being issue-focused and solution-oriented, and therefore it can be posited as a process as well as an artefact. It should reveal how a set of artefacts can help with solving the focal issues and how the artefact as well as their construction process can be evaluated. In addition, informed by March and Smith (1995), the artefacts include four types, such as constructs, models, methods and instantiation. Fischer *et al.* (2012) also further proposes four important perspectives of evaluating the outcome of design science artefacts and process, including validity, utility, generalisability and innovativeness.

There are seven principles highlighted in the design science research (adapted from Hevner *et al.*, 2004).

- Design as an artefact: it delivers an operationalisable artefact for review and evaluation

- Problem relevance: it contributes a solution for solving a focused issue
- Design evaluation: it evaluates an artefact based on experts' review with a rigorous frame
- Research contributions: it produces a set of clear-stated and justified contributions
- Research rigor: rigorous methods are applied during the process of construction and evaluation
- Design as a search process: it seeks an effective solution toward a defined issue
- Communication of research: it is necessary to present the artefact to the relevant audience for collecting further inputs of demands and experience

Since design science research produces artefacts as an outcome of a research process as well as a solution to specific issues, it consists of two main types activities, including the phases of building and evaluation. The building phase refers to constructing an artefact as a prototype solution toward the defined issue. The evaluation phase refers to assessing the artefacts based on experts' review in terms of their performance and impacts. Therefore, design science research often adapts research techniques of behavioural sciences to understand users' demands, execute the artefact development with the engagement of stakeholders, and evaluate based on experts' involvement (Hevner and Chatterjee, 2010).

The framework of design science research includes three basic pillars, such as environment, IS research and knowledge base (Figure 3-1). It indicates that the inputs from environment and knowledge needs to be incorporated into the process of artefact development (within IS research). It also reveals that the outcome from IS research can generate impacts on both environment by delivering a new application and knowledge base by renewing the prior knowledge. The pillar of environment refers to the inputs captured from people (stakeholders), organisation (context) and technology, especially the emerging issues and demands. The pillar of knowledge refers to the theoretical foundation and existing methodologies relevant to the defined issues, which contributes to the applied knowledge to support the development of artefacts. The pillar of IS research contains the activities of building and evaluation, which works as a medium to incorporate the existing theories and methodologies to the research context as well as to develop a solution to address the captured issues from the environment.

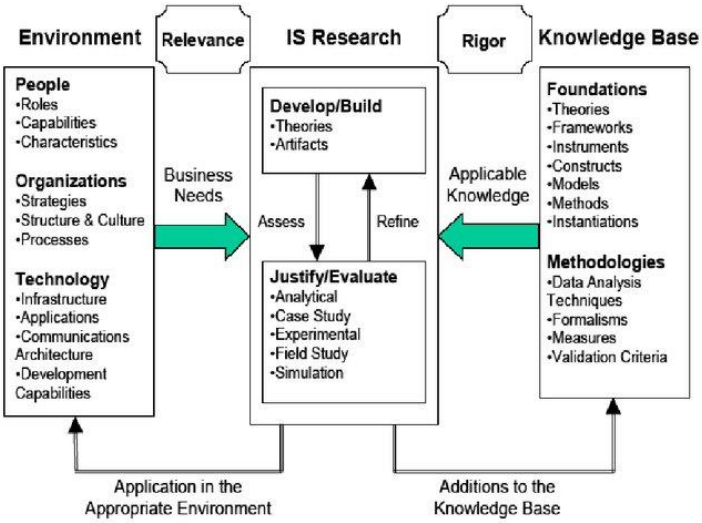


Figure 3-1 Design Science Research Diagram (Hevner et al.*, 2004)*

3.4.2 Case Study Research

Case study research is conducting in-depth investigation through a small amount of cases, in contrast to the survey method which involves a huge amount of cases. Case study research can be further defined as an inquiry method to investigate a contemporary phenomenon within a real-life context, for the purpose of enabling research to consider the contextual factors during the process of designing artefacts (Benbasat, Goldstein and Mead, 1987). The strategies of case study include single case, multiple cases, holistic case and embedded case (Saunders, Lewis and Thornhill, 2015). Single case refers to selecting a unique and typical case, where a desire phenomenon can be sufficiently observed. Multiple cases include several cases which can empower the generalisation of the findings. The holistic case means that researchers select an organisation as a whole for study where the phenomenon appeared within the organisational context. The embed case is built upon the holistic case, which indicates that, within an organisational context, some sub-unit cases will be involved in order to obtain more detailed information.

Referring the explanation of case study research from Yin (2009), five components of case study research will be utilised in this research (Table 3-3).

Table 3-3 Five Components of Case Study Research

Components	Further Address in this research
A study question	This research will associate the choice of case study approach with the research question, especially evaluating if research question(s) can be considerably sufficient addressed in the selected cases.
Study proposition	The study proposition of this research will be examined in the context of case studies.
Unit of analysis	This research will select a certain number of cases where research questions will be feasibly discovered.
The logic link among data and proposition	A collection of approaches will be used in the research to collect data, including interviews, documentation and observation.

The criteria of result interpretation	In this research, the evidences collected from case studies via a collection of models and analytic techniques.

The case study method can be further divided into four categories based on the objectives of investigation, including exploratory, illustrative, cumulative and critical instance (Saunders, Lewis and Thornhill, 2015). Illustrative case study, also known as descriptive case study, utilises a few examples to demonstrate what a scenario (and its characteristics) is or what potential impacts the newly proposed framework can possibly bring. It serves the objective where it helps readers understand the unfamiliar situation and provoke a further discussion. The exploratory case study, also known as the pilot case study, is often conducted before a large scale of investigation. It serves the objectives to enable researchers to be familiar with the research context and establishes a preliminary understanding as a part foundation of further research. It echoes the process of abductive research where exploratory case study helps with establishing a preliminary hypotheses and proposition, and illustrative case study can further refine them by iteratively participating into further observation. The cumulative case study refers to the collection of case study across different sites as well as different time points. It serves the objectives of longitudinal research via observing the potential changes among different geographical positions, as well as the differences between past and present. The critical instance case study refers to where the research concentrates on a few scenarios with unique patterns. It reveals little interest in the generaliability of research process and results but focuses on building in-depth understanding of a specific research context.

3.5 Research Design

3.5.1 Adapted Research Approach

This research adapts abduction as the main research approach. It has applied for the overall research design as well as constituting a process of developing IDV. Abduction portrays a logical reasoning process which reveals the process of new knowledge and theory generation and can further help researcher to further associate with the research paradigm (interpretivism), research strategies (design science and case study) and research methodology and techniques (qualitative methods and interview). This research aims to construct a framework that can guide the development of interactive data visualisation to facilitate the understanding, interpretation and sense-making of data patterns. The nature of this research is to be developed as a solution for incorporating the complex user demands into the process of interactive data visualisation development. Therefore, abduction can be regarded as a high-level guideline to help with the implementation of design science research. The researcher firstly organises the preliminary hypotheses and propositions based on the inputs from the environment and knowledge basis. The researcher then incorporates inputs into the iterative process of building and evaluating artefacts. Finally, the refined or newly constructed hypotheses and proposition can be sent back to environment as an application to resolve the focused issues and to knowledge basis as a renewal

input of upgrade knowledge. In contrast, deduction focuses on examining the existing theories with results of acceptance or rejection, while induction focuses on finding an explanation for a certain phenomenon through an in-depth investigation in a certain research context. Saunders et al. (2015) further points out that induction cannot be implemented without the input of prior knowledge and facilitation from relevant experience. Ochara (2013) also identifies that when provoking inductive or deduction researches, the researchers' prior knowledge can trace back to researchers' background, such as culture, individual experience and education, which directly or indirectly influence the research development. Thus, in this research, abduction has been selected as the research approach, which empowers the researchers to start with preliminary knowledge and continuously refines knowledge via iterative observation and interaction during the process of building and evaluating artefacts. It can offer an application to solve focused issues during the interactive data visualisation development as well as new hypotheses and propositions to knowledge basis, which can be further used for inductive and deductive research as prior knowledge. At the same time, abduction will be used in the IDV development for guiding the requirement articulation and deployment of visualisation representation and interactive mechanisms. Inspired by (Liu and Tan, 2015), the iterative nature of abduction can continuously refine the requirement discovery and visualisation development, which enables the final artifacts to fulfil the users' demands to the best degree. This sub-chapter will provide further details of the utilised research paradigm, methodology and techniques in this research.

3.5.2 Adapted Research Paradigm

The research question stated in the chapter one provokes the researcher to conduct the following actions.

- To build a basic concept and by reviewing the relevant literature on the development of data visualisation.
- To specify the logic reasoning approach of data visualisation process.
- To incorporate the norm-based approach into the construction of data visualisation framework.
- To illustrate the capacities of the proposed framework in the scenarios of facilitating visualisation development.
- To evaluate the performance and potential impacts with experts' experience and opinions.

The nature of this research focuses on constructing a subjective understanding of process of interactive data visualisation development as well as mapping a set of IDV development mechanisms to each stage during the process. It enables the IDV development process as well as the final products to address the demands of different stakeholders in an appropriate pattern.

Interpretivism paradigm is adopted in this research. The visualisation process is regarded as a socio-technical system, where multiple objects from both two aspects need to be considered by incorporating multiple means. Thus, interpretivism allows the researcher to interpret the process where users interact with data visualisation for fulfilling different purposes, based on the underlying structures of logical reasoning process that shapes the observed user behaviours. Moreover, other than objective factors,

some subjective factors (incl. users' demands, intentions and interpretations of organisational and social pressure) will be taken into account. This differs from positivism, which mostly relies on the observation and experience; interpretivism leads the research focus on both the observation and the mental process after observation which reveals the underlying structure causing the observed user behaviours. It echoes Burke (2007) who points to the interpretivism as the most suitable paradigm for information research paradigm due to its in-depth consideration of the impacts from people and their context. In terms of the connection between interpretivism and research approach, interpretivism is very often associated with induction, which enables researchers to summarise and interpret the phenomenon based on observation. Interpretivism can be associated to abduction as well, since the generating new understanding is not a "one-off" action, but requires an iterative process where the output of observation needs to compared with the prior understandings for configuring new questions, and further observation will be needed to collect more information for validating the understanding. Therefore, consistent with the "innovative abduction" (Roozenburg and Eekels, 1995) which indicate the iterative observation and continuous refinement of understanding can help consolidating the interpretation, this research will utilise abductive research approaches under the interpretivism as a research paradigm.

The detailed information related to the utilisation of interpretivism will be discussed in Table 3-4, in terms of ontology, epistemology and methodology.

Table 3-4 Ontological, Epistemological and Methodological Assumptions

Underpinned assumptions	Description in this research
Ontological assumption	The development of interactive data visualisation is a socially constructed process which incorporates multiple stakeholders, their prior knowledge, information demands, interpretation purposes and contextual pressure affecting their sense-making. Hence, the nature of IDV development can be discovered from the individual's perspective with sufficient consideration of their contextual information.
Epistemological assumption	Information, such as prior understanding and user demands, can be perceived via communication with different participants. Knowledge can be generated based on understanding the interaction between participants and visualisation artefacts. Then, the obtained knowledge can be further adopted as a solution to facilitate the development of IDV as well as an output to enrich the knowledge basis of interactive data visualisation.
Methodological assumption	Qualitative methods, such as semi-structure interview and participant observation, are mainly utilised in this research.

3.5.3 Adopted Research Methods and Techniques

This research has adopted abduction as its research approach leading the overall research design. Interpretivism has been adopted as research paradigm which can further associate with the ontological, epistemological and methodological assumptions. Interpretivism often connects to the induction paradigm. Inspired by Lukka and Modell (2010) and Petty, Thomson and Stew (2012), the abduction process will be associated with the interpretivism paradigm to establish an understanding of IDV development process and continuously refining it with iterative observation in this research. Ho (1994)

also points out that abduction can associate with qualitative research methodology, since qualitative understanding of reality can reveal rich details with greater flexibility of discovery compared with quantitative methodology. As stated in sub-chapter 2.4.1, abduction, as a logical reasoning process where researchers can identify and explain the puzzled phenomena or surprises with the aid of their prior knowledge and then refine the explanation with continuous observation, will utilised in this research on two positions. Firstly, abduction, as an overall research approach, leads the overall research design, including selection of research methods and techniques which associates to the design science research process for offer step-by-step guideline for understanding the process of IDV development as well as "building and evaluation" of design science (discussed in the following section). Secondly, abduction will be employed to portray the overall process of IDV development, which will be examined in the exploratory case study in Chapter 4 and will be detailed in the conceptual framework in the Chapter 5.

Design science and case study are adopted as dominant research strategies in this research along with abductive process. Since the design process can be perceived as a complex process of scientific discovery with the involvement of multiple stakeholders, it has been employed to portray the development of IDV. Referring to Table 3-5, the basic principles of design science research will be addressed in this research,

Table 3-5 Seven Principles of Design Science Research

Principles	Further address in this research.
Design as an artefact	The research will produce a viable artefact (interactive data visualisation).
Problem relevance	This research will associate the artefact with the relevant business problems.
Design evaluation	The research will evaluate the artefact based on a set of criteria based on its performance and impacts toward issues.
Research contributions	This research will offer clear and verifiable contributions on the theoretical, methodological and practical aspects.
Research rigor	This research will incorporate a collection of conditions and criteria for constructing and evaluating the design.
Design as a search process	Other than producing artefacts, this research will also portray a process to demonstrate how an effective solution was discovered.
Communication of research	The artefacts in this research will be presented to problem-related audiences and feedbacks collected from current and potential users.

Exploratory and illustrative case study is utilised in this research as another key research strategy. The deployment of case studies is associated with the abductive process of overall research design. The exploratory case study (detailed in Chapter 5) is employed to apply the initial understanding, a preliminary case study scenario, for the initial examination, where the outcome can be used as an input for constructing the conceptual framework (detailed in the Chapter 6). The illustrative case study (detailed in Chapter 7) is applied to further refine the conceptual framework with continuous engagement in the case study scenarios, including interacting with different participants and collecting their feedbacks when engaging with the artefacts. The outcomes of illustrative case study consist of two

streams, including an application (portrayed in the artefact) to facilitate the development of IDV and a refined understanding to enrich the knowledge basis of IDV research. Figure 3-2 demonstrates the research design of constructing IDV development framework, consisting of three important phases: (1) Initial Research Definition and Design, (2) Observation and Construction, and (3) Evaluation and Refinement. Meanwhile, different knowledge can be generated in each part of design science process. In the first part, the knowledge generation is mainly related to configuring the initial theoretical propositions. Based on the investigation and review of relevant studies, a series of data visualisation models and theoretical propositions can be extracted and incorporated into designing the initial version of FINVID. In the second part, the knowledge generation is mainly related to constructing a framework and principles of IDV development. The theoretical propositions from the first part will be further developed during the process of constructing FINVID, with users' and experts' inputs. The knowledge of IDV development will evolved from three key theoretical propositions to an integrated framework which cover the development process, mechanisms, and techniques. In the third part, the knowledge generation is mainly related to the construction implications of IDV, which can be applied to the IDV development in a wide range of scenarios. Through experts' validation and users' feedback, FINVID will be refined and concretised to be a method to develop IDV.

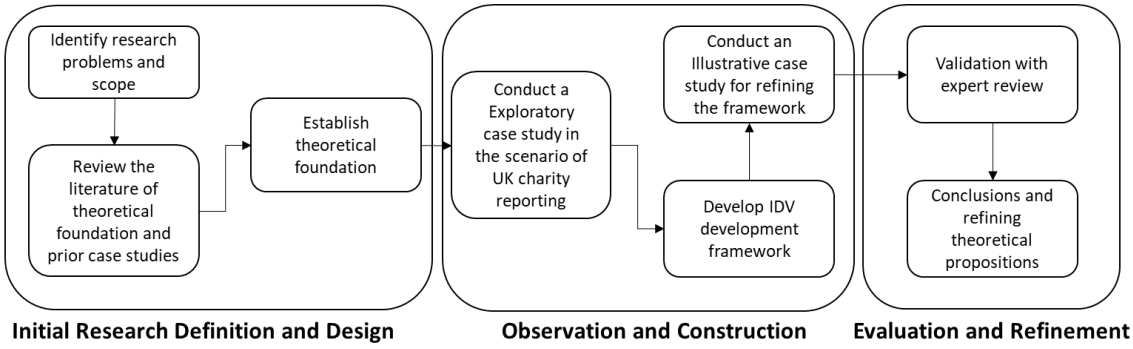


Figure 3-2 Research Design based Design Science Research

Initial Research Definition and Design

This research scope and focused issues are identified in this phase, along with an extensive literature review to lay a theoretical foundation for the further stages of research. The literature review consists of two parts. The first part (Chapter 2) mainly focuses on the theoretical foundation of data visualisation which can work as a set of general guidelines for configuring the plausible explanations for the puzzled phenomenon. The second part (Chapter 3) mainly focuses on the prior case studies of portraying data visualisation process for analysing their different research focuses, interpretation and suggestions to visualisation development. The specific actions taken in this phase can be listed as follows.

- Reviewing the relevant theories and approaches of data visualisation design.
- Critically discussing the contributions and limitations which appeared in the data visualisation development process demonstrated in previous research.

In addition, three principles of design science research are mainly applied in this stage. The first principle is "problem relevance", which indicates that this research focuses on construct solutions toward the theorical and empirical issues pinpointed in the IDV development (detailed in Chapter 1). The second and third principle are "Design as an artefact" and "Design as a search process". In this research, further developed from Liu and Tan (2015), the development of IDV can be understood as a design and can eventually lead to the artefact which solves the issues in the reality.

Observation and Construction

Case study research is incorporated in this phase of research for observation purposes, where various scenario-based data can be inputted as well as multiple stakeholders can be involved for observing their interaction with data visualisation. Two case studies are conducted in this research, including an exploratory case study based on the scenario of facilitating the accountability of the UK charity reports, and an illustrative case study based on the scenario of helping an energy drink company C (abbreviated as C company) with selecting the target markets for internationalisation.

The first case study is for exploratory purposes, where the initial observation is conducted for examining and developing the prior understanding based on the literature review. The UK charity report is selected as the case study scenario, where it is compulsory for UK charities to disclose its information to the society and enable multiple stakeholders to supervisor their operation, management and development, for the purpose of justifying their charity status and tax benefits granted by the government. For the evaluation of charity reporting practice, the term of "accountability" has two-fold meaning, including "being accountable to" (reveal information to the stakeholders) and "being held account to" (empower stakeholders to understand and act upon the disclosed information). Pinpointed by prior research, the part of "being held account to" has been a challenge for the majority of UK charities in their reporting practices. In this research, interactive data visualisation is used to facilitate the charity reporting practice, and 15 voluntary participants are involved in interacting with the data visualisation, where the research can observe the interaction process and their feedback of using interactive data visualisation. The data for constructing the data visualisation is based on secondary data sources, including the dominant information demands of individual donors collected from (Connolly and Hyndman, 2013, 2017; Hyndman and McConville, 2016) and the operational data of charity collected via the open source API of Charity Commission. Informal discussion and "think-loud" session have been conducted during the case study for collecting the participants' feedback and observe their interactions with data visualisation, which leads a primary data source in this case study. The detailed information of research procedure, data collection and analysis techniques are detailed in Chapter 5, followed by Chapter 6 where the refined theoretical propositions configured in this exploratory case study are utilised to construct the IDV development framework.

The second case study, the market research project of Company C constitutes the illustrative research. Various data sources including market research data from the market agents and several rounds of user interview are employed in this case study (descripted in sub-chapter 7.2). Various data analysis techniques such as norm analysis and document analysis are discussed in the sub-chapter. Also, the final deliverable of this project, which is a prototype of marketing intelligence, can be regarded an artefact for further portraying the process of designing interactive data visualisation for business purposes. Thus, after completing this project based on users' requirements, all records can be used as materials to refine theoretical framework where abductive reasoning approach has been used in the project of designing data visualisation and to help facilitate the interoperation between visualisation users and designers. Overall, the research design in the second phase is associates with design science research principle of "research rigour", which indicate that this research applies a well-structured process with sufficient consideration of participants' view and their contextual information when constructing the design.

Evaluation and Refinement

Following the process of abductive reasoning, the final phrase is therefore to evaluate the artefact as well as the process of IDV development. Inspired by Fischer *et al.* (2012), the evaluation will be conducted from four perspectives, including validity, utility, generalisability and innovativeness. Since the IDV development framework has been partly illustrated in the case study of global market selection, the users' feedback and relevant records in the case study can demonstrate its validity. Besides, the expert review sessions are also incorporated for the purpose of evaluation based on experts' experience and knowledge. Overall, 10 experts with appropriate knowledge and experience related to IDV development are involved into the review, including the executive members of C company, operational team of C company, project consultant, marketing professor and IS professor.

The details of the procedure and results of the evaluation are detailed in the Chapter 8 and the outcomes of evaluation are further inputted to Chapter 8, where the overall research is evaluated and discussed from the perspectives of contributions and limitations. This phase reflects three design science research principles. The first and second principle are "research evaluation" and "research communication", which means that the artefact and its construction process will be reviewed by experts to reveal its performance and impacts based on experts' knowledge and experience, especially when the framework has no chance of being fully implemented in a real scenario. The third principle is "research contributions", which indicates that the contributions of this research are discussed in the Chapter 9 from theoretical, practical and methodological perspectives.

3.6 Data Collection

In terms of data collection, the Company C project contributes the mainstream of data for this research at the preliminary stage, including market investigation result from market agents, public data from

NGOs and experts' opinions. In addition, data will be collected from the company's public database, e.g. registration information published in the Charity Commission's official website. Finally, for the purpose of involving users' feedback to further improve the framework, the method of user interview, especially semi-structured interview, will be applied in this research.

Project-based Data Collection

In the illustrative case study, required by the Company C project, a market intelligence tool has been built for comparing marketing attractiveness among different markets. Therefore, users purchased the data of global market investigation for this research, which are published by a series of high-profile market research agents, such as Canedean research and Euromonitor. In addition, data from different sources and with different dimensions will be supplied for conducting further market research. Thus, the Company C project provides data for carrying out the preliminary research and configuring the conceptual framework.

Public Data Collection

For other two case studies, public (open source) data will be incorporated for demonstrating the framework of abductive data visualisation design. There are two main reasons for choosing to visualise public data. Firstly, public data, such as charity and crowdfunding information, contains the feature of huge volume and high complexity, but carries necessity and urgency for the general public to understand the data and perceive the information. Secondly, required by the statute (e.g. Charity Act 2011), public data should be available for public inspection on websites and by post enquiry. However, insufficient capacity of interpreting data hinders the public from conducting an inspection and even fulfilling the right of information, which also pinpoints the necessity of this research.

User Interview

Referring to the literature review where the insufficient research focus has been placed on social factors of data visualisation, this research will involve the method of user interview to capture users' dynamic demands, differentiated intentions and implicit social norms for presenting visual representation. To be specific, a semi-structured interview will be applied to obtain users' opinions toward visualisation design, which will be used as a guideline to further perfect the visualisation design until the demand has been fulfilled. Other than one-to-one interview, group interview or workshops will be utilised to create an atmosphere of co-design where all stakeholders' requirements can be taken into account based on priority, which is associated with some successful cases discussed in previous research findings (Liu, 2000; Bonacin, Baranauskas and Liu, 2004).

3.7 Analysis Techniques

Based on the different features and analysis demands of data, there are various techniques for data analytics that can be applied to process the data for visualisation (Table 3-6).

Table 3-6 Data Analytics Techniques

Data Analysis Techniques	Application in this research.
Norm analysis	Profiling users' demands, purposes and contextual information in the norm format of "What, Why, Where, When, Why and How". Identify the trigger and effect relationship (condition, agent and action) to assist the design of interactive functions.
Document analysis	Extracting data by reviewing the reports published by market agents, charity governors and crowdfunding platforms. Categorising data based on their semantic meanings (the business domain knowledge from previous research will be incorporated). Dimensioning data based on users' requirements and intentions. Presenting data representations to users and collecting feedback for further improvement.
Statistic Indexing Approach	Integrated with domain knowledge, such as global marketing strategy, charity competitiveness analysis and crowd-funding platform credibility analysis, clustering data to different high-level indexes. By embedding interactive function, the high-level indexes will be able to be broken down and inspected by different subdivisions, such as by their business meanings (semantic), by scenarios and purposes (pragmatic), and by social norms. During the process when users are interacting with data visualisation tools, both explicit and implicit demands, intentions and social norms can be further captured and then serve as a basis for further improvement.
Qualitative Analysis of Interview Script	Other than quantitative analysis which merely deals with numerical data, conducting qualitative analysis obtains information of demands, intentions and social norm from users' feedback. Capturing users' feedback during the focus group or workshop and analysing it is based on the dimensions of socio-technical design (e.g. technical fitness; semantic interpretability; pragmatic fulfilment; and awareness of social norm).

3.8 Summary

This chapter has covered the discussion of key components of the adapted research framework in this research, including research paradigms, research approaches, research methodologies, research strategies, research methods and techniques. This chapter also highlights the role of logical reasoning as a general guidance of overall research design as well as a key guideline to lead the process of IDV development. In this research, the process of constructing IDV framework is understood as an abductive process where the research can start with the preliminary understandings established from the literature review, and then refine the theoretical hypotheses and propositions during the iterative observation. In addition, the process of constructing an IDV artefact is also seen as an abductive process where the participants bring their prior knowledge to the visualisation and continuous refine their knowledge during the iterative process of interacting with data visualisation. Design science research is a key research strategy to define the process and major activities of constructing IDV framework, along with the case study strategy which allows research to further establish the theoretical proposition of IDV development process in the exploratory case study and to illustrate them in the illustrative case study for evaluating the performance and impact of the IDV artefact and development process. Therefore, the abduction process enables the research to establish the theoretical propositions in the initial case study,

and then the theoretical propositions can further be used to construct the framework of IDV development. In the second case study, the abduction allows the researcher to continuously refine the framework with iterative observation, which can finally enable this research to product an application to resolve the focal issues in the reality and enrich the knowledge basis of IDV development.

4. Case Study – Interactive Data Visualisation for Developing Accountability in Charities in the UK

This chapter illustrates the development of an interactive data visualisation (IDV) and further develops the theoretical propositions of this research in the scenario of UK charity annual report for facilitating the accountability. The content of this chapter is preliminarily derived from the published work of Li and Liu (2016). In sub-chapter 3.5, the overall research approach follows the abductive reasoning process where the theoretical propositions generated based on the prior knowledge, from literature review and case studies review, can be continuously refined and evolved based on iterative observation, and eventually produce new knowledge. Therefore, this exploratory case study can carry the theoretical propositions from Chapter 2 and Chapter 3 to a real case scenario for examination and refinement. They then can be inputted to Chapter 6 for further construction of conceptual framework of IDV development. Moreover, echoing the design science research method (Figure 3-2), this exploratory case study positions on the second phrase as an initial discovery of potential solutions based on a real scenario observation, which can further lead to the solution configuration in the next stage.

In this research context, an exploratory case study is implemented in the scenario of a UK charity annual report for the purpose of observing the process of developing an interactive data visualisation with the aid of real-life data and user feedbacks. According to Saunders, Lewis and Thornhill (2015), an exploratory case study can be defined as a study to discover the details in what is happening as well as to acquire new insights. There are two contributions which should be pinpointed. Firstly, an exploratory case study allows research to conduct an initial trial of newly developed theoretical propositions and framework in a real-time scenario, which gives an opportunity to observe the fitness between the theoretical and concrete spheres. Secondly, the exploratory mindset allows enough flexibility for researchers to capture the new insights, which can help enhance the theoretical framework with widening its consideration of all relevant factors and scenarios.

To be specific, the overall purpose of this exploratory case study is to examine and refine the theoretical propositions generated from the literature review. The following sub-chapters illustrate the procedure of the exploratory case study, including the research background, data collection and visualisation

development. Finally, the theoretical propositions are revised based on the user feedback and evaluation, and then they are utilised as an important input for the conceptual framework development in Chapter 6.

4.1 Background to the Case Study

Charity can be defined as a type of organisation which is established for charitable purposes only, for example, the advancement of education, health or saving of lives (Hyndman, 1990; Hyndman and McConville, 2015). Due to the aim of delivering public benefits to the society, it is permitted to collect financial donations and voluntary inputs from the social public and to receive the tax benefits granted by the government (McConville, 2017). In 2019, there are 183,299 charities registered in England and Wales. They raised charity funds worth £77.07 billion from the charity-related activities, such as voluntary donation, fundraising campaigns and charity shop trading, which consists 3% of annual GDP of 2019 in the UK. At the same year, £74.30 billion has been spent on the charity-related activities for directly or indirectly delivering public benefits. Other than the charity income, around 1.13 million employees are working in the charities and around 4.2 million registered volunteers contribute to the charity activities on a regular basis (Charity Commission, 2019). The data above echoes the statement from Connolly, Hyndman and McConville (2013) that charities in the UK have gathered a significant amount of social resources, which can enable them to play an important role advancing social welfare and equality.

However, the charity scandals have undermined donors' as well as volunteers' trust in the charity, since donors are not sure if their donation and contributions will be used for charitable purposes and to what degree that positive impacts or performance are generated from the charity activities (Hyndman and McConville, 2018). With the development and implementation of SORP (Charity Commission, 2015), it is therefore required to make transparent the financial and operational information in their annual reports; in brief, how have they collected and spent the charity money, what purposes they have been serving, and what impacts they have made to the whole society. It is believed that compulsory disclosure on the annual report will help different stakeholders, such as institutional and individual donors, volunteers, beneficiaries and regulators, supervise the charities' behaviours and ensure their activities to be on track under social pressure (Hyndman and McConville, 2015).

The annual reporting practice requires charities to disclose information on a regular basis and on multiple platforms, such as websites, newsletters and even social media, in order to ensure the information of its fundraising, operation and governance to be accessible by the social public. SORP mainly regulates the financial (quantitative) information the charities disclose and offers little guidance towards the way of disclosure as well as the associated qualitative information for explanation. Therefore, it leads to the issue where stakeholders, especially the individual donors and beneficiaries with little financial and statistical background to decode the financial figures in the annual report, might

have found it hard to understand the disclosed information. To some extent, even though the charities disclose the required information on the annual report, the selection and presentation of disclosed information cannot empower the majority of stakeholders, especially individual donors, volunteers and beneficiaries, to understand the content and implement the supervision towards the charities' activities.

The above issues of charity disclosure can also be traced back to the theories of accountability and stakeholder management.

Accountability refers to an obligation that an organisation has to inform the relevant stakeholder with the information about what has been done, current ongoing activities and what will be planned for the future (Jackson, 1988). In the context of charities, they should discharge the relevant information of fundraising, operation and governance activities to the social public for being supervised. As pointed out by Stewart (1984), accountability has two folds of meanings, including "account to" referring to providing information and "hold to account" referring to that stakeholder can evaluate its performance and impacts based on the disclosed information. In the case of charity reporting practice, the disclosure of annual report can fulfil the aspect of "account to", but since the information on the annual report cannot be easily understood by the stakeholders, it cannot let stakeholders "hold to account" – to judge what has been done by charities and then be able to supervise their activities. In the background of charity scandals, 60% of interviewed individual donors express their uncertainty and even concerns if charities are able to utilise their raised resource properly to serve the common good, which indicates the stakeholder might lose their trust and "vote on their feet" without understanding the charity disclosed information sufficiently. Connolly, Hyndman and McConville (2013) further point out that good accountability can be helpful to charities for avoiding scandals and enhancing their trustworthiness among the public.

In addition, the charity reporting issues can also be addressed based on stakeholder theories, which encourage an organisation must proper respond to the diverse demands from stakeholders in exchange for their support (Donaldson and Preston, 1995). Referring the general definition of stakeholders from Freeman (1984), stakeholders indicate anyone who influences and is influenced by the charities' activities. Therefore, it is important for charities to keep stakeholders being informed for obtaining their supports as well as being accountable to the influences toward stakeholders. Based on the narrow definition of stakeholders from Cornell and Shapiro (1987), charities tend to focus more on the stakeholder groups with legitimate impact, such as regulators on their reporting practices, which causes the reporting content to merely serve the public auditing purposes but cannot be easily understood by the social public. It hinders the social public, such individual donors and beneficiaries, from supervising the charities' activities, and leads to charity scandals in some circumstances. Finally, inspired by the stakeholder salience and dynamics from Mitchell, Agle and Wood (1997), a charity report cannot merely cater to the key stakeholders with legitimate impacts, but need to be more flexible to fulfil the

diverse demands of a wider range of stakeholders, since they might grow with the power to impact charities' resources and operation and urgently need to be informed due to the impact of charity activities on their benefits. The claim that a charity report needs to be accountable to the diverse set of stakeholders is supported by the following research pieces which pinpoint the necessity and significance of disclosing charity information to different key stakeholder groups (Table 4-1).

Table 4-1 Key stakeholder groups for charity reports

Key stakeholder group	References
Major funders and contributors	(Mayston, 1992; Bouckaert and Vandenhove, 1998; Hyndman and McDonnell, 2009)
Beneficiaries and general public	(Friedman and Mason, 2004; Cordery and Baskerville, 2005; Hyndman and McMahon, 2010; Wellens and Jegers, 2011)
Supporters and Volunteers	(Edwards and Hulme, 1995; Knox and Gruar, 2007; Anheier, Hass and Beller, 2013; McConville, 2017)
Individual donors and institutional donors	(Connolly and Hyndman, 2013, 2017)

The discussion above justifies the necessity of disclosing charity information which can enhance its accountability to the social public as well as establish a trustworthy relationship with different stakeholders in order to obtain their support. However, the key issue remains where the charities lack an efficient method to disclose information. The traditional annual report has a fixed sequence, selection and layout of disclosing information, which cannot cater to the diverse stakeholders by allowing them to query the information they need. Also, for some charity reports which contain a large amount of information constituting more than 100 pages of content, without interactive data filtering, selection and navigation, the overloaded information prevents users from identifying the key data patterns as well as focusing on the key information. It further causes the issues of "over-accounting" where, although information is accessible, users are not enabled to participate in and make use of it.

In this research, interactive data visualisation will be applied to address the issue of charity reporting practice by enabling the disclosed information to be presented in an interactive visualisation interface where users can interactively query the data based on their information demands, in order to improve their capability of making use of the disclosed data. At the same time, the theoretical propositions generated from the literature review are examined and refined in this case study based on the observation and feedbacks of participants (Table 4-2). They will be further utilised in Chapter 6 in order to construct the conceptual framework.

Table 4-2 Three key propositions of IDV development

Key theoretical propositions	Explanation in the context of IDV development
Data visualisation development can be portrayed as a norm-centric process.	The IDV development process needs to strike a balance between interpretation and data, where norms can help with capture the social perspective (incl. information needs, purpose and context) of information needs in order to integrate them with the visualisation techniques.

Data visualisation development contains an abductive reasoning process.	The IDV development needs to strike a balance between process and artefact where it should not only focus on making a visualisation artefact, but it also needs to embed an abductive process for acquiring users' changing information needs and to keep addressing them in the visualisation.
Data visualisation needs to serve for users' knowledge exploration.	The IDV needs to strike a balance between the objective and subjective perspectives of visualisation. It needs to reveal the patterns of dataset via graphical means and it also needs to enable users to explore and refine the knowledge while interacting with the visualisation.

The implementation of the exploratory case study consists of the following stages: sub-chapter 4.2 describes the data sources and data collections methods for visualisation development and feedback analysis; sub-chapter 4.3 reveals the overall process of visualisation development and user participation; sub-chapter 4.4 analyse the users' feedback for examining and refining the theoretical propositions; and sub-chapter 4.5 summarises the revised theoretical propositions which would be used as an input for the theoretical framework construction in Chapter 6.

4.2 Data Collection Methods and Data Sources

In this study, the combination of primary and secondly data will be incorporated into the empirical research.

Primary data refers to the data specifically collected for the undertaken research project (Saunders, Lewis and Thornhill, 2015). In the preliminary study, the primacy data will be collected via observation, especially through a "think aloud" session. Observation helps investigate the ongoing event in the research context, and perceiving the physical setting, key participants and their actions, with specific focuses on events, sequence, processes and emotions (Corbin and Strauss, 2014). Inspired by Lee *et al.*, (2016), a "think aloud" session can be defined as a method of empirical research, which allows participants to talk through the real-time thoughts and feedback in addition o interacting with the artefacts, during the whole process of participating into the experiment. Researchers can sit beside to observe the interaction and taking note of their comments and feedbacks when being engaged with a specific function. By the end of research, the researchers can produce an exploratory pathway map for reflecting the users' journey as well as a set of notes for recording the key feedbacks and comments. Via conducting descriptive analysis of note content, the key information can be captured for revisiting the theoretical propositions.

In the "think-aloud" sessions, ten participants were involved in interacting with the charity data visualisation and provided their feedback during and after the interaction. Snowball sampling method has been applied in this case study for selecting ten participants. The participants are business school students in undergraduate or postgraduate courses. They need to have a basic understanding of charity

as a concept, including charity's purposes, activities, and fundraising demands, which can help them to evaluate the charity information conveyed by the visualisation. They also need to live in the UK for at least 6 months and can give one or two examples of UK charities as an evidence of basic understanding of charities in the UK. However, the participants are not required to have through understanding of charities, since they are expected to build their understanding of charity performance via interacting with the visualisation. The basic profile of participants in the case study one is listed in (Table 4-3) and the sample of transcript and notes can be found in Appendix A.

Table 4-3 Basic Profile of Participants

Participant ID	Courses Enrolled	Familiarity with UK Charities
P1	MSc Accounting and Finance	Basic (understand the concept of charity, but has never engaged in charity activities)
P2	MSc Business Information Management	Basic (understand the concept of charity, but has never engaged in charity activities)
P3	BSc Accounting	Intermediate (volunteered in a charity)
P4	BSc Business Management	Basic
P5	MSc International Business	Intermediate (worked in an assignment related a charity-related topic)
P6	MSc Management	Basic (understand the concept of charity, but has never engaged in charity activities)
P7	MSc Corporate Finance	Basic (understand the concept of charity, but has never engaged in charity activities)
P8	MSc Real Estate Management	Basic (understand the concept of charity, but has never engaged in charity activities)
P9	MSc Construction Management	Basic (understand the concept of charity, but has never engaged in charity activities)
P10	MSc International Marketing	Intermediate (worked in an assignment related a charity-related topic)

A laptop with 15-inch LED screen (1280x1024 screen resolution) and a wireless mouse were used. A "think-aloud" were held for each participant and the researcher sat beside the participant to observe their interaction and note down their feedback. The "think-aloud" session consists of the following steps. Firstly, the researcher briefly introduced the context of exploratory study to the participants in order to help the participants to fill the defined roles and to provoke their following actions. It includes the following information in Table 4-4.

Table 4-4 Key information for research briefs

Predefined information	Detailed explanation.
Predefined Role	Individual donor with a preliminary intention of supporting a charity.
Predefined Context	To justify if the charity is worth supporting based on the information captured from the annual report visualisation.
Expected actions	Read through the visualisation and interact with the interface to query more information.

	Provide feedback or comment for explaining the interaction e.g. What information you are looking for? What other information can you associate with? Whether you need to know further details? What other information you wish to be incorporated? Compare interactive visualisation and traditional report, and describe how the interactive functions help with your sense-making of the report content?

Secondly, the participants were guided to interact with the visualisation, and to make comments and feedback while conducting each interaction, including the information they have perceived and the motivations for further interaction. The researcher took notes and provoked more feedback from participants by giving instructions or asking questions e.g. please describe your thoughts and actions while interacting with the visualisation. Thirdly, after the interaction with visualisation, the research would go through the notes with participants for clarification and to add extra information. Finally, a semi-structure interview was conducted with each participant for understanding the role of norms and knowledge exploration during the interaction with visualisation. The entire procedure of "think-aloud" session for each participant lasted around 40 minutes.

Secondary data refers to the data originally collected for other purposes, but it can be further analysed from different perspectives for adding different understanding and interpretation (Saunders, Lewis and Thornhill, 2015). In this exploratory case study, the secondary data will be incorporated for the main purposes of mapping and structuring stakeholders' demands as well as input charity report data into the interactive data visualisation design. For the stakeholders' information needs, a series of research results (Table 4-5) can be adapted into the research design for guiding the initial design of interactive data visualisation, and the further adjustment will be based on the real-time feedbacks during the "think-aloud" session via interactive functions.

Table 4-5 List of initial information needs

Information needs	Explanation
Charity income	The total amount of income and its breakdown of sub-fundraising categories (Connolly and Hyndman, 2017)
Charitable expenditure	The total amount of charity spending and its breakdown of sub-spending categories (Connolly and Hyndman, 2017)
Efficiency (comparison)	Comparison between income and fundraising expenditure. Comparison between income and charitable expenses in the previous year (Sargeant, Lee and Jay, 2009)
Output	The immediate products and services offered by the charity (Connolly, Dhanani and Hyndman, 2013; Hyndman and McConville, 2018)
Output-based effectiveness	A comparison between an output and pre-set target (Breckell, Harrison and Robert, 2011)

In order to construct the prototype of interactive data visualisation for a charity report, the charity related data are extracted through Charity Commission Open API. The Charity Commission is the governance body of the registered charities in England and Wales, which gathers charity data and makes them available for any enqueries. Based on the requirement of SORP, all UK charities need to disclose their income, expenditure, bank balance, assets, liabilities and other significant transactions. Therefore, the

financial data can be streamed via the Charity Commission API for visualisation construction. In addition, the corporate governance and operation performance information can be extracted from the annual report database from the selected charities database. In this exploratory research, the following information demands are selected to construct the prototype: income, expenditure and performance of charitable activities. The development of IDV aims to help individual donor to understand of income/expenditure status, fundraising/charitable spending efficiency, and performance of charitable activities of the selected charity (Table 4-6).

Table 4-6 Key variables collected from Charity Commission API

Variable	Query name (examples)	Definition
Charity registration ID	registrationNumber	The charity registration number.
Charity formal name	formalName	The registered legal name the charity is known as.
Charity categories (serial number)	classes	Lookup values that the category of charity work is associated with.
Charity categories (description)	areaOfBusiness	Description of the area where the charity implements its activities.
Charitable objectives (purposes)	aimsActivities	Description of charity aims and activities.
Annual income	fIncome	Annual total income of the selected charity.
Main income sources	IncomeType	Major categories of income sources.
Detailed description (fundraising activities)	DecFundAct	Description of fundraising activities with picture illustration.
Annual expenditure	fExpenditure	Annual total expenditure on charitable activities.
Main charity activities	incChar	Major categories of charitable expenditure.
Detailed description (charity activities)	DesCharAct	Description of charitable activities with outcome evaluation.
Beneficiary cases	BeneCases	Disclosed beneficiary cases for justifying the outcomes of charitable activities.

4.3IDV Development

In the exploratory case study, the IDV development follows the traditional linear process of visualisation development, which includes four steps: requirement articulation, data collection, visual representation programming, interaction with users. These four steps can be further mapped with a 3-tier software architecture, which can reveal the IDV development from technical perspectives, including data sources and software applied in this research (Figure 4-1).

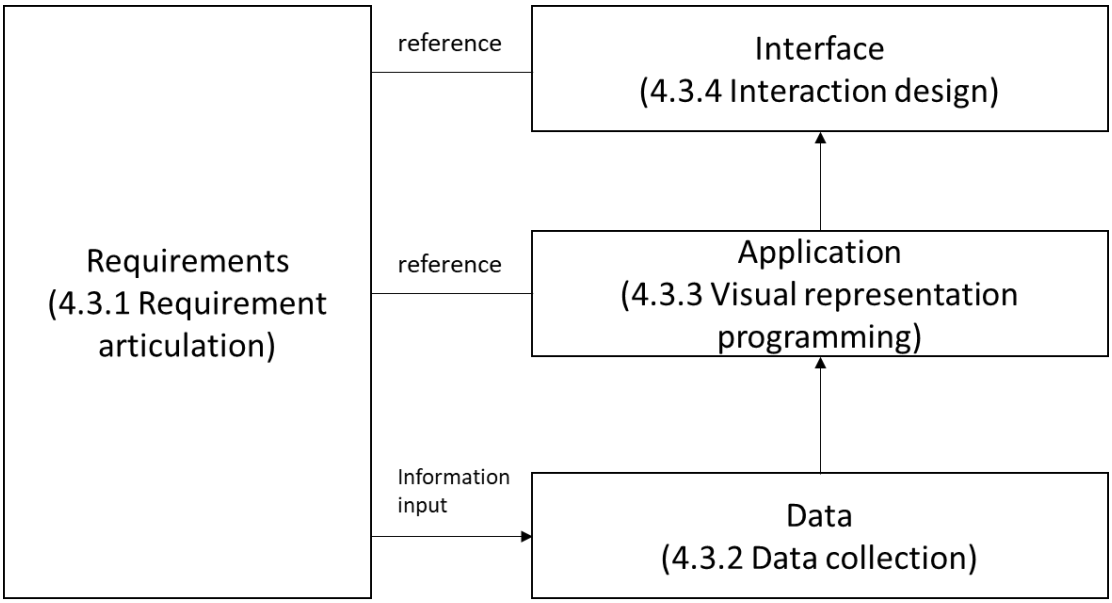


Figure 4-1 Four steps of IDV development

4.3.1 Requirement Articulation

The first step is requirement articulation where the users' requirements would be identified and articulated in the norm specification for supporting the visualisation development. As is shown in (Figure 4-1), the users' requirements would associate with data (which data sources should be included), application (how data can be modelled for visualisation) and interface (what visualisation and interactive functions would be deployed). In this exploratory study, all participants were assumed to play the stakeholder role of individual donors and were assumed to be engaged in the scenario where they are considering justifying if a charity is worth supporting based on its disclosed charity information. Among the diverse demands, understanding fundraising, expenditure and public benefits tends to be the prioritised focus for the majority of individual donors. Understanding fundraising-related information enables donors to select the charities in an actual financial need, which prevents the individual donation to be over-concentrated on a few charities at "the top of the list". In addition, the interpretation of expenditure information enables donors to identify the main purposes where a charity spends their funds and contributions that it potentially brings to society. Individual donors tend to choose the charity which

share the same vision and values. Finally, both qualitative and quantitative information of public benefit will be used by individual donors to assess the performance as well as the social contribution and then assist the decision-making process if they might support the charity. The information needs of individual donors are elicited based on the prior research (Connolly, Dhanani and Hyndman, 2013), which will be listed in Table 4-7. Therefore, the data visualisation design will mainly focus on the selected information above to facilitate the individual donors' interpretation via visual means.

Table 4-7 Initial information needs for IDV development

Information needs	Key requirements
Annual charity income	To evaluate how much money has been raised by the charity and to compare it with the expenditure for justifying surplus or deficit.
Annual charity expenditure	To evaluate how much money has been spent on charitable activities and to check the breakdown value on each category.
Fundraising efficiency	Comparison between amount of raised fund and fundraising expenses.
Output (performance)	To view the direct output of charitable activities for evaluating the charity performance.

Norms can be used a set of structured documents to record information demands, which can help designers understand the requirements and further address them in the specific designs. Inspired by norm analysis (Tan, Liu and White, 2013), the information demands would be further articulated in the format of the norm. A norm format consists of five components, including context <whenever>, condition <if>, agent <then>, deontic operator <is> and action <to> (Table 4-8).

Table 4-8 Norm specification in the context of IDV development

Whenever	If	Then	Is	To
Context where a data visualisation will be viewed	Condition where an interactive function will be triggered	The role assigned with the stakeholders	Permitted (read and write access), obliged (read access), prohibited (no access)	Retrieve information

Based on the information demands of fundraising, expenditure and public benefits, the following norms are articulated for the purpose of guiding the design of interactive data visualisation (Table 4-9).

Table 4-9 Information demands of fundraising as an example

Tags	Where	If	Then	Is	To
F1 (Fundraising)	Initial viewing fundraising activities	The fundraising option is selected	Individual donor	Permitted	View the annual amount of raised fund
F2 (Fundraising)	Further viewing fundraising activities break down	The "fundraising activity" option is selected	Individual donor	Permitted	Break the total amount by activities

F3 (Fundraising)	Further viewing fundraising time period (break down)	The “fundraising time period” option is selected	Individual donor	Permitted	Break the total amount by time periods
F4 (Fundraising)	Further viewing fundraising comparison (with average level in the charitable sector)	The “sector average” option is selected	Individual donor	Permitted	Compare the total amount of raised funds with the sector average
F5 (Fundraising)	Further viewing fundraising efficiency (compared with fundraising cost)	The “fundraising efficiency” option is selected	Individual donor	Permitted	Compare the total amount of raised fund with fundraising expenses
F6 (Fundraising)	Further viewing fundraising amount (compared with expenditure amount)	The “fundraising/expenditure” option is selected	Individual donor	Permitted	Compare the total among of raised fund with total expenditure amount

4.3.2 Data Collection

The data collected for constructing the visualisation is extracted from the Charity Commission API and the annual report database of selected database. Since Tableau was applied as the main software platform to develop the visualisation programme, the ETL (Extract, Transform and Loading) process was facilitated by Tableau functional components. The data was extracted from the external database (Charity Commission and annual report), stored and transformed in Tableau SQL databases, loaded into Tableau data warehouse for the following data query and visualisation development. Based on the norms articulated in the step 1, the corresponding data were collected and mapped with different norm categories (Table 4-10).

Table 4-10 Key variable for IDV development

Variable	Data sources	Mapped norm categories
Charity registration ID	Charity Commission	Basic information
Charity formal name	Charity Commission	Basic information
Charity categories (serial number)	Charity Commission	Basic information
Charity categories (description)	Charity Commission	Basic information
Charitable objectives (purposes)	Charity Commission	Basic information
Annual income	Charity Commission	Fundraising
Main income sources	Charity Commission	Fundraising
Detailed description (fundraising activities)	Annual report	Fundraising
Annual expenditure	Charity Commission	Expenditure
Main charity activities	Charity Commission	Efficiency
Detailed description (charity activities)	Annual report	Output

Beneficiary cases	Annual report	Output

4.3.3 Visual Representation Programming

After step 2, the relevant data has been collected from the external data sources and stored in the Tableau SQL database for data query. Based on the norms articulated in step 1, the data process models were established in step 3, which can be help querying the data and loading for visualisation. The modelling techniques include sum() for summarising the selected categories of datasets, average() for averaging the data within the same categories, output() for presenting the textual information on the interface and where() for selected the data based on certain criteria (Table 4-11).

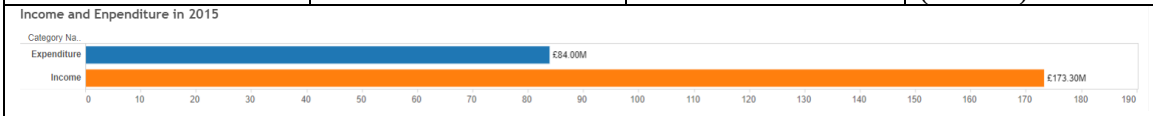
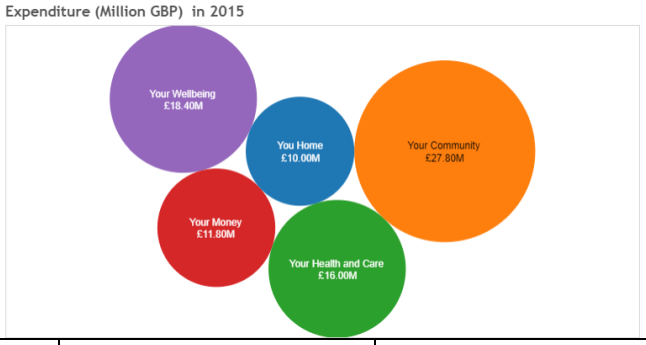
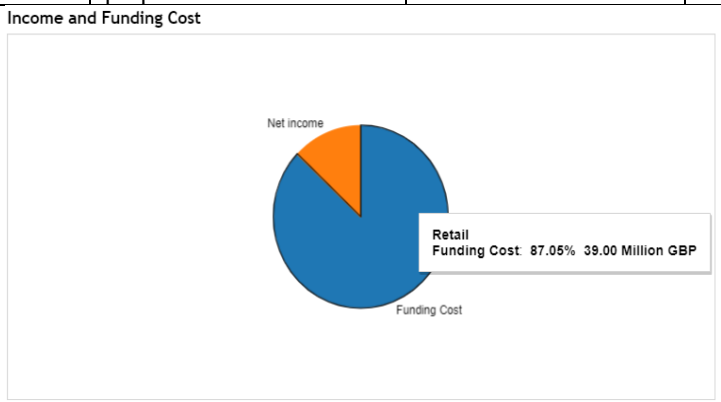
Table 4-11 Data processing models

Information needs categories	Information needs	Data processing model
Fundraising	Viewing amount of annual income	Sum (Annual_Income) where (Charity_ID)
	Viewing average annual income of charities in the same charity category	Average (Annual_Income) where Classes_ID
Expenditure	Viewing amount of annual expenditure	Sum (Annual_Income) where Charity_ID
	Viewing average annual expenditure of charities in the same charity category	Average (Annual_Exp) where Classes_ID
	Average the amount of expenditure on each category of charity activity	Sum (Annual_Exp) where Charity_ID, Charity_Activity
Fundraising efficiency	Comparing annual income and annual expenditure	Sum (annual_income) and sum (annual_exp)
	Comparing amount of raised fund with fundraising costs on each category of fundraising activity	Sum (annual income) and sum (fundraising_exp) where Charity ID and Fundraising_activitiy
Output	Presenting the description of each charity activity category	Output (Description_CharityAct) where Charity ID and Charity_activity
	Presenting the associate case studies of each category of charity activity	Output (Beneficiary_case) where Charity_ID and Charity_activity

Based on the established models, the dataset can then be transferred as an input for visual representation construction. Different visual representations were selected based on the associated norms, which reveals the users' requirements in a structured way (Table 4-12). It can ensure the main functions of visual presentation to match with the main actions elicited in the norms (see the bold text). Furthermore, the different variables from the charity dataset were addressed via the different key feature of visualisation (e.g. colour, position and size).

Table 4-12 Visual representation selection

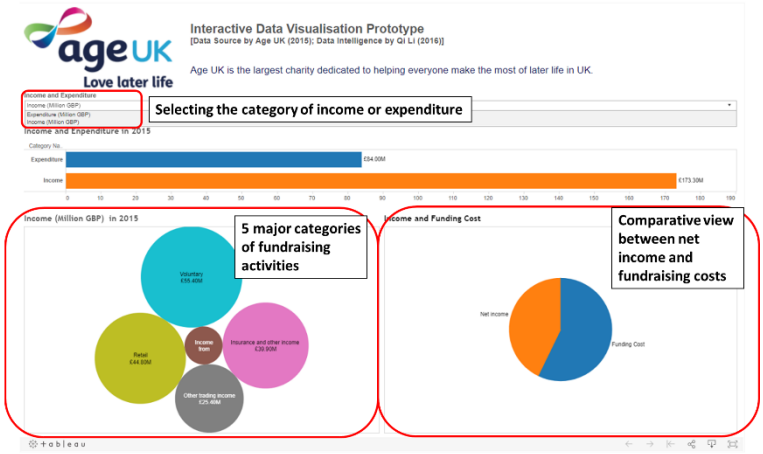
Visual representation	Main functions	Associated norms	Key features

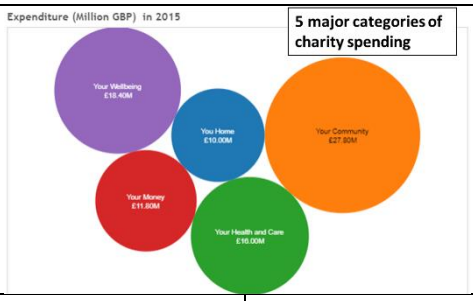
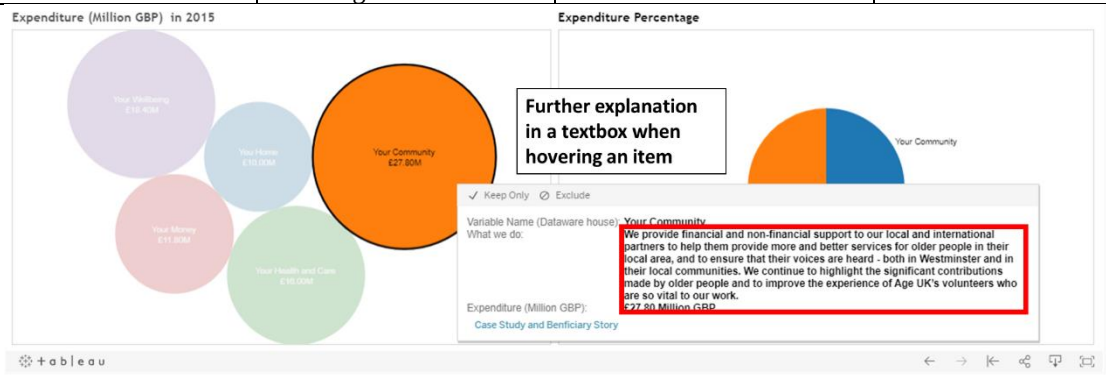
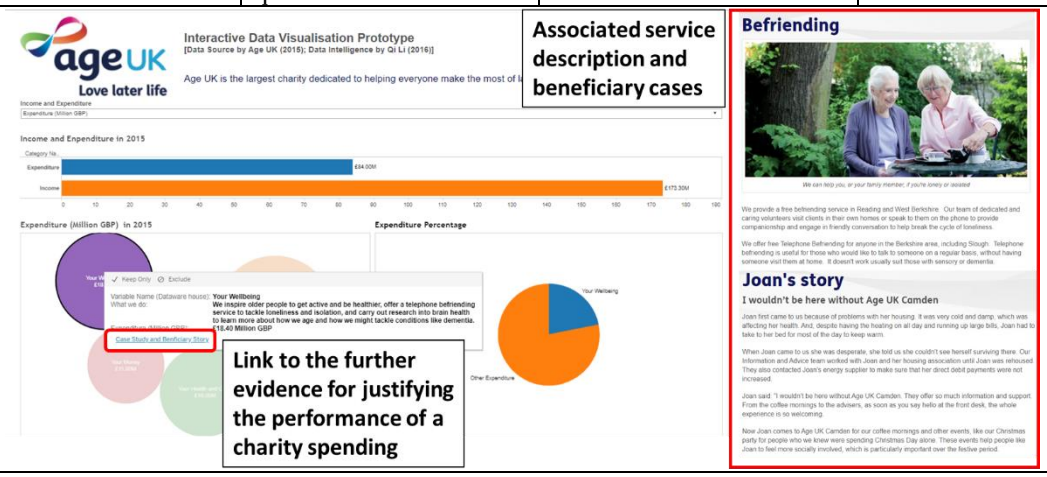
Bar Chart (Bar_1)	Bar chart associates with the demonstration of **comparison**. It includes either horizontal or vertical bars for comparing the figures across categories.	**Viewing** the amount of income and expenditure. **Comparing** the amount of raised fund with the expenditure.	Colour and position refer to the category of income and expenditure. Size refers to the sum of income or expenditure. The horizontal scale marks with the currency unit (£million).
			
Bubble Chart (Bubble_1)	Bubble chart associates with the demonstration of **comparison and relationship**.	**Viewing and comparing** the amount of charity spending on different charity activity categories. **Identifying** the biggest proportion of charity spending.	Colour refers to the categories of charity activity. Size refers to the sum of total spending on the selected charity activity.
			
Pie Chart (Pie_1)	Pie chart associates with the demonstration **composition**. It shows the propositions and percentage across different categories. It is often used to analyse the composition with 2-3 proportions.	**Viewing and contrast** the amount of raised fund and fundraising costs.	Colour refers to the categories of amount of raised fund and fundraising costs. Size refers to the percentage of each category.
			

4.3.4 Interaction Design

Once the visual presentations had been constructed with the guidance of the associated norms, interactive functions were then deployed on the visualisation interface in step 4. Interaction in the context of data visualisation refers to the functions that enable user to address their ab-hoc information needs by sending data queries via the interactive interface, such as filtering and selecting data (Li and Liu, 2018). In this exploratory case study, different interactive functions can be applied for further addressing the information needs from the users. At the same time, since interaction allows users to address their further information needs while viewing the visualisation, it also provides an opportunity to observe the users' potential abductive reasoning process where they might conduct an initial observation with prior knowledge and propositions, and configure new propositions or questions by engaging in the interactive functions. The initial design of interactive functions is based on the readers' demands from Connolly, Dhanani and Hyndman (2013) and Connolly and Hyndman (2017), which articulate what data readers are interested in within a charity report and basic intentions of interpreting the data for justifying if they will support a charity or not. The selected interaction functions, associated norms and "what-if" scenarios are listed in Table 4-13.

Table 4-13 Interactive function design

Interactive function	Explanation in the context of data visualisation	What-if scenarios	Associated norms
Selection	Providing users with the ability to mark the interested data items for keeping track of them.	If the income category is selected, what is the view of fundraising activity composition, and fundraising activity efficiency?	To identify the major fundraising activities and to evaluate the efficiency based on the comparison between raised funds and funding costs.
Example			
Overview	Demonstrating the entire collection of datasets for helping users establish a big picture of overall patterns e.g. major composition.	(If) under the expenditure category, what are the major components of charity spending?	To identify the key activity where the charity spent the majority of their funds.

<table>
<tr><td colspan="4"> 
</td></tr>
<tr><td>Annotation</td><td>Attaching more associated textual data in a textbox for revealing more explanatory information; this can be triggered by mouse hovering.</td><td>If a certain category of charity spending is selected, what is the further explanation of the charity spending?</td><td>To find more details of what the charity is and what services the charity provides to beneficiaries.</td></tr>
<tr><td colspan="4"> 
</td></tr>
<tr><td>Elaboration</td><td>Showing more associated evidence via embedded hyperlink to reveal more supplementary information e.g. associating qualitative information with a quantitative index.</td><td>(If) for a certain category of charity spending, what is its impact (performance/contribution) toward beneficiaries?</td><td>To evaluate the charity's contribution to the society based on beneficiary cases (incl. the activity details, generated benefits and social impacts).</td></tr>
<tr><td colspan="4"> 
</td></tr>
</table>

Based on the developed interactive functions, the navigation path can be further designed to address the information needs embedded in the norms. Navigation can be defined as an embedded guidance where users can associate one visual representation with another and establish a holistic understanding (Segel

and Heer, 2010). Based on the norm articulated in step 1, two navigation paths were simulated in the IDV development, where the interactive functions can help with link them together (Table 4-14). The navigation paths are generated based on the readers' information needs identified in the prior studies. For examples, some donors are interested in charity income and fundraising activities. They would like to find out how a charity raise fund, how much they can raise each year, and by what activity they have obtained most of fund. The navigation paths have been applied in the initial design of IDV artefact in the case study. In addition, based on the navigation embedded in the visualisation, the researcher can further observe the users' reasoning process and identify whether users follow one navigation path for making sense of data or whether they shift between two navigation paths for further addressing new questions and propositions, which can be captured for identifying the potential abductive reasoning process in the visualisation.

Table 4-14 Navigation path design

Navigation sequence	Visual representation
1	Bar_chart: Overview of income and expenditure
2	Bar_chart: Selection of income category
3	Bubble_chart: Comparison of different fundraising activity
4	Pie_chart: Percentage of raised funds of each category
5	Annotation (textbox): Detailed information of a fundraising activity e.g. major funders and fundraising activities (news or reports)
Navigation sequence	Visual representation
1	Bar_chart: Overview of income and expenditure
2	Bar_chart: Selection of expenditure categories with a comparison the total amount with average of its charity category
3	Bubble_chart: Comparison of different spending projects
4	Pie_chart: Proportion of the selected charity spending in the total charity expenditure
5	Annotation (textbox): Brief description of charitable activities and their associated charitable objectives
6	Elaboration hyperlink (extra qualitative data): News or reports for revealing the outputs and outcomes of charitable activities

4.4 User Actions and Feedback

Inspired from the NOVIS model by Lee et al. (2016), other than the predefined navigation paths, users' activities (incl. interaction with visualisation and provide feedbacks) during the "think-aloud" sessions can be further organised into five main categories (Table 4-15).

Table 4-15 Five main user activities in the "think-aloud" sessions

Category of users' actions and feedback	Explanation in the exploratory case study
(1) Encountering visualisation	Users initially look at the overview of visualisation
(2) Constructing a proposition	Users construct an initial proposition based on the observation of visualisation
(3) Exploring visualisation	Users interact with the visualisation interface for discovering more facts and detailed information from the visualisation e.g. following the navigation path to find more details
(4) Generating new questions	Users would like to address new questions and find more information in the visualisation

(5) Drawing Conclusions	Users draw conclusions based on observation of visualisation

Based on the observation of users' actions and their feedbacks, their sense-making paths can be revealed in Figure 4-2, which demonstrates the whole journey that they were engaged with the visualization. The arrows show the transitions of users between activities and the numbers in the brackets indicate the amount of transition among activities based on researcher's observation and feedback records. For example, there were ten participants triggering the second activity after the first one. In contrast, after the second activity, eight participants continued with the third activity, and two participants directly went to the fifth activity for drawing conclusions.

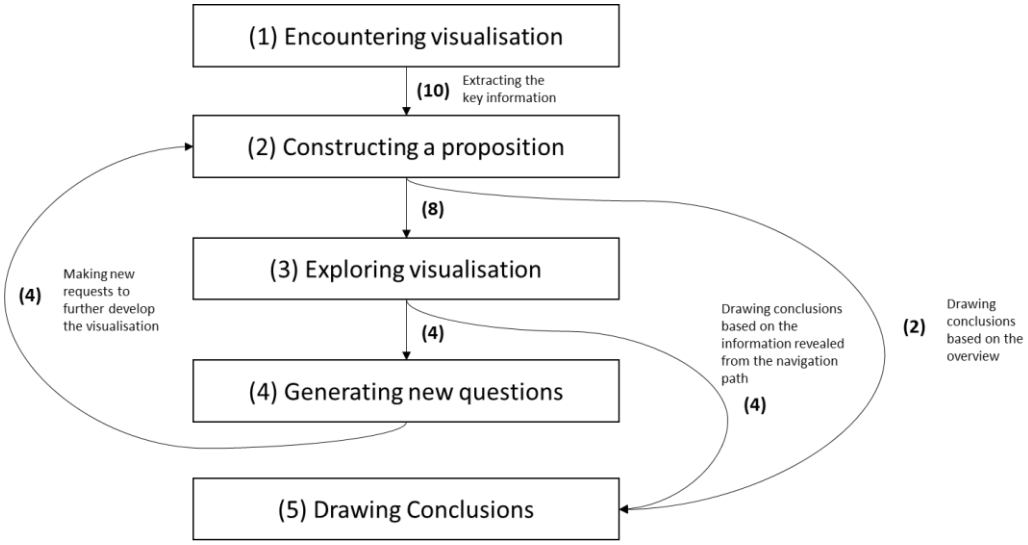


Figure 4-2 Sense-making paths

In following sub-sections, the results of observations and user feedbacks in each activity are summarised with representative quotes from users.

The first activity is encountering visualisation where the users initially provide an overview of the visualisation, where they can view of total income and expenditure of the selected charity, justify the status of surplus or deficit, and compare the income or expenditure figure with the charity section average (e.g. the average annual income in senior caring charity section). While users were viewing the visualisation, they were also encouraged to talk through the information that they perceived from the visual representation. Although it is the initial stage of think-aloud session, the majority of users made feedback based on what they were able to perceive from the visualisation, and even expressed the initial impression towards the selected charity. P1 commented, "The income is higher than the expenditure, which means they should have enough cash in the bank balance to sustain their charity activities". P3 commented "I may not support this charity since they have merely spent half of their raised fund for charitable activities. It seems those money can be used for other charities, instead of being saved in the bank". At the same time, he added "I would like to discover further how you spent their money and how you maintain the unused funds".

The second activity constructs a proposition, where users can construct their propositions based on the initial view of visualisation (overview page). The propositions can be applied as a basis of conclusions as well as a further guidance for the exploration in the following stage. In this exploratory case study, 2 out 10 users decided to draw conclusions directly without having further exploration of data visualisation, since they had obtained enough information to construct their conclusions. P9 commented "I knew this charity before, and I agree with what they are doing. Based on the visualisation, they seem to manage their finance well with higher-than-average income and a reasonable amount of surplus." P4 commented "I think they might have raised more funds than what they need. I therefore consider supporting other charities in needs. If I were a donor, I might not spend too much time on checking the operational details. That's enough information for me". In addition, 8 out 10 users decided to continue with further exploring the visualisation for acquiring more information. P7 commented: "Although it shows more income than expenditure, I would like to know how did they raise the funds"; P6 commented "Since the charity spent more expenditure than the average, I would like to know in which activity they spent their money"; P10 commented "It seems a lot of money spent last year, and therefore I would like to know what benefit they offer to the society"; P2 commented "The total amount of money does not really interest me. I would like to see more details about how they spent and how they help others".

The third activity explores visualisation where users can acquire further information via interacting with visualisation interface. Followed the navigation paths, the users can associate one visual representation with others for elaborating a certain topic with more details e.g. zooming from total amount of expenditure to different categories of charity spending. 4 out of 8 users felt ready to draw conclusions after exploring the data visualisation via the interactive functions and navigation paths. P6 commented "After going through all 5 categories of fundraising activities, I found that the most of fund comes from the voluntary donation which is also most efficient and cost-saving approach to raise funds compared with others"; P7 "Although charity shop is very popular around the area I am living, it is consider a costly approach to raise fund"; P3 commented "Building and maintaining senior community and offering senior support/caring comprise the charity's main activities, which I highly apricate especially on the trend of aged society"; P10 commented "Associating the beneficiary story to the figure of charity spending gives me a deep insight how the charity makes an impact on our society".

In addition, 4 out 8 users also addressed new information needs while interacting with data visualisation. P6 commented "Since in last year the charity raised more money than what you have spent, I would like to know what actions they would take to maintain the funds"; P7 commented "Other than the charity spending, I would like to see the managerial expenditure for the charity. High managerial expenditure might cause charity scandal like internal corruption"; P10 commented "If I were going to donate to a charity, I would like to see its future development plan and how much money they might require for sustaining it".

The fourth activity generates new questions, where users can address new questions which the current data visualisation cannot answer and might require extra data inputs or modification of visual representations. Out of all 10 users, 4 users attempted to address new information requests explicitly for further developing the data visualisation. They expressed their interest to participate in the further development process, since they might find more information needs while interacting with data visualisation. They also believe with the continuous inputs of information needs, and the revised data visualisation can provide richer information and fulfil the individual donors' information needs better. P8 commented: "It is ready hard to address all information needs at the initial stage, since I might not really know I really want to see"; P10 commented "Based on what I can see from the visualisation, I might want to know further details. Therefore, the interactive functions can help me to find more detailed information".

At the same time, based on the new questions addressed by the users, the researcher selected 2 of these to articulate in a norm format and present it back to the users. The users confirmed that data visualisation development needs to be demand-driven where data visualisation needs to fulfil the information needs, instead of displaying irrelevant information that make users hardly focus on the important one. Moreover, the articulation of information needs in the norm format can elicit more details of information needs, such as trigger (when the information should be presented), the role of users (who needs the information and can access to the information) and specific actions (interaction with the data visualisation for obtaining the information). Compared to the narrative approach of collecting information needs, the norm approach offers an organised way to manage information needs and to guide the development of visualisation and interactive functions.

For example, P3 addressed the following information need: "I would like to know the amount of managerial expenditure, its percentage in the total expenditure and composition of different managerial categories". It can be articulated in the norm format in Table 4-16.

Table 4-16 Norm specification (example)

Whenever	If	Then	Is	To
Exploring the detailed information of expenditure	The expenditure category is selected	Individual donor	Permitted	View the annual amount of managerial expenditure
Exploring the detailed information of expenditure	The composition of expenditure is selected	Individual donor	Permitted	View the percentage of annual managerial expenditure in the total expenditure
Exploring the detailed information of managerial expenditure	The managerial expenditure is selected	Individual donor	Permitted	View the composition of managerial expenditure (sum and percentage)

4.5Theoretical Proposition Revisited

The results generated via observation and users' feedback are applied to evaluate and refine the theoretical proposition established based on the literature review. Hermeneutics analysis is mainly utilised to interpret the results derived from the observation records and feedback transcript. Hermeneutics analysis refers to a method of interpretation which enables researchers to establish an extended understanding based on the observed phenomenon as well as documented conversation (Olson and Carlisle, 2001). It can be applied in the research of information system field, where research can make sense of complex individual view with a consideration of contextual information (Tomkins and Eatough, 2018). Thematical analysis is also incorporated to lead the research focuses on the prominent themes (e.g. contents related to the theoretical propositions like interaction, norm and abduction) and generate further interpretation on the qualitative data.

Based on the feedback during the semi-structured interview, the participants generally confirmed the contribution of visualisation and interactions towards understanding the content of charity annual reports compared with the traditional report-based approach. For the specific contributions of visualisation, the users point to out the advantages of visual perception when using visualisation. Although the traditional report-style approach might contain all the legitimately required contents, the visualisation can quickly present the data and its dominant patterns via the graphic means, which makes users easier to perceive the information compared with reading through them via textual format e.g. P2 commented: "Compared with reading though a 100-page report, I prefer to have a quick glance via visualisation where I can easily find information via shape, size and colour in diagrams". Also, they confirmed that the visualisation can help with filtering the irrelevant information by highlighting the key data patterns, which is known as de-cluttering e.g. P5 commented: "It (visualisation) also help me avoid unnecessary information, since I can easily spot the prominent patterns of dataset. Then if I need to know further details, I can read further via the annotation and associated diagrams". For the specific contributions of interactive functions, the users imply that interactive functions help to address their information needs (e.g. find more details) and to see different results under different conditions (e.g. fundraising efficiency under the fundraising category). Other examples are as follows. P2 commented : "When I saw the total amount of annual income, I would like to know more via the interaction where the income come from and what the main campaign activity is for the charity to raise fund."; P8 commented: "the pop-up box (annotation) provides more explanatory information for me to understand what the figure means, and it can also help me see the charity's performance and impact by linking to a beneficiary case".

Three theoretical propositions are evaluated and refined based on the results derived from the exploratory case study, which are demonstrated as follows.

4.5.1 Theoretical Proposition 1: IDV Development is a Norm-centric Process

The first theoretical proposition is that "data visualisation can be understood as a norm-centric process". A norm can be defined as a type of knowledge representation which guides agents to perform a certain action in a certain context. It also enables the agents and their actions to be characterised in social norms, based on view of organisational semiotics, with consideration of the semantic meaning, purposes and social context. In the context of IDV development, norms can be utilised to identify and articulate the information needs to integrate the context (where), the purposes of interpretation (if), the agent (then), the permission of presentation and interaction (is) and specific functions (to). Therefore, the norm needs be recognised as a centric role to lead the IDV development, since the selection and deployment of visual representations and interactive functions need to serve for the users' information needs e.g. P2 commented "I hope data visualisation can present the data relevant to my questions"; P10 commented "Too much (overloaded) information would really confuse me, and I therefore wish visualisation can help highlight the dominant data patterns and filter the noises based on my needs"; P4 commented "I will not spent too much time on reading the report, so I want the visualisation to be designed based on my questions".

Compared with the narrative description of users' information needs, a norm offers a structured approach to capture the social information associated to the information needs, such as context and purposes. Based on the users' feedback, it is supported that the incorporation of social norms can help the IDV development become more aligned with users' information needs. e.g. P2 commented "Norm is a good approach to identify the purposes. Although we might focus on the same theme, like expenditure, different purposes might lead us different way of interpretation. For example, I would like to know in what activity the charity spent its money in order to justify if there is potential issues of high managerial costs or internal corruption; other may want to see the contributions and impacts generated by the charity spending in order to justify its performance"; P6 commented "I do not have enough time to go through the detailed contents, so I just want to see the big categories of their charity activities and service and see if I agree with their purposes and values",

However, when the documented norms were presented to the users, they further point out that without the background of IS research or training/using experience, it is hard for them to directly understand the norm structure and map their information needs into the according positions. Therefore, the users still prefer to address their information needs in a narrative format and this requires an intermediate, such as a consultant, to lead the articulation and documentation. Moreover, when 35 norm records were articulated based on the information needs, it was challenging for the researcher to map all norms to each specific visual representation and interactive functions. Although in this case study, the majority of norms applied in the visualisation design were developed based on functional requirements derived from the prior studies, the process of generating and applying norms was demonstrated to the

participants. Also a few examples were made during the conversation in order to let participants understand the role and functions of norms. For example, P2 stated "I am very interested in the amount of managerial expenses of charities as well as its percentage in the total expenses. If a charity spent the most of its money on managerial expense, it might indicate the issue of management inefficiency or potential likelihood of corruption scandal. Therefore, it will be helpful to visualise the components of managerial expenses with description and examples. A reference list or benchmark, like 35%, can be marked in managerial expenses for justifying if the managerial expense is higher than the normal". A set of norms were articulated based on P2's statement, especially to record contextual information via <Where> and participants' intention via <To>.

Tags	Where	If	Then	Is	To
E5	Viewing amount of managerial expenses, since high management expense might reduce the spending on charitable activities	The option of management expense is selected	Individual donor	Permitted	View amount of managerial expenses
E6	Comparing amount of managerial expenses with an average of charities within the same category for justify if it is higher than the normal	The option of management expense is selected	Individual donor	Permitted	Compare the amount of managerial expense of selected charity with the average
E7	Viewing the sub-categories of managerial expenses for clarifying where the managerial expenses were spent	The view of sub-categories is selected	Individual donor	Permitted	Compare the percentage of different sub-categories of managerial expenses
E8	Requesting the descriptions and examples of managerial expense categories for justifying if the expense is reasonably and legitimately spent	A sub-category is selected	Individual donor	Permitted	Link to the description of sub-categories and disclosed cases showing how the money were spent

Therefore, it is necessary to categorise norms and associate the categories with different activities of IDV development, such as data collection, data modelling, visual representation construction and interaction development.

In summary, based on the results derived from the exploratory case study, it is observed that the IDV development can be regarded as a norm-centric process, where norms help identify and articulate the information needs with a social perspective including the consideration of meaning, purpose and context. It helps the IDV development align with the users' information needs with the right level of interpretation, for the right purposes, and in the right context. At the same time, it is also suggested that when it comes to implementation, since the norm format is different from the generic way that users

used to address their needs, it is still necessary to incorporate an intermediate to coordinate the elicitation, articulation and documentation of information needs in a norm format. Furthermore, the six main categories of norm can be further incorporated for assisting the norm management and mapping the norm to the different activities in the IDV development.

4.5.2 Theoretical Proposition 2: Abductive Reasoning Process is embedded in IDV Development

The second theoretical proposition is that IDV development process can be portrayed as an abductive reasoning process, where users can observe the phenomenon and generate initial propositions with their prior knowledge and then continuously refine the proposition while engaging with iterative observation. Abduction is one of main research reasoning approaches, which allow researchers to refine and generate new knowledge based on the iterative observation. In this exploratory case study, it is observed that users' engagement with interactive interface and them further addressing the new questions can be regarded as a reflection of abductive reasoning e.g. "Based on the general comparison between income and expenditure, I can see the a surplus. Therefore, I would like to know what charity has done to raise too much money"; "I saw the expenditure is higher than other charities within the same charity class, so I would like to see how the charity spent their money". In addition, after interacting with the visualisation interface, the users posted new questions for further developing the data visualisation by adding new data sources and modifying visual representation to better fulfil their information needs e.g. "Although the major compositions of charity spending are demonstrated, I would like to further check if the managerial expenses is very high or not, since I wish the raised funds to serve for the people in needs"; "After viewing how much money the charity spent, I would like to see how many beneficiaries the charity has served and in which countries".

Although the design of interaction and navigation path can help users address their new requests by revealing or associating more data and detailed information, there are still some new requests which were not captured in the initial norm articulation and were not covered by the initial data collection and modelling. Therefore, in the following conceptual framework construction, it is necessary to incorporate the abductive reasoning process into IDV development with activity to continuously engage users to capture the updating information needs e.g. new information needs might be generated while engaging with the visualisation. It is also agreed by the users that continuous involvement and input of information needs can enable the visualisation to fulfil the information needs in a dynamic pattern. Even the users themselves might not be able to express all their information needs at the initial stage, and the needs might be updated with the progress of observation. Echoing the discussion in sub-chapter 5.4.2, the information needs can be initially captured in a narrative format and further transferred to the norm format with a specification of norm categories.

In summary, based on the results generated from the exploratory case study, it is observed the abductive reasoning process can be embedded in the IDV development, since users can refine and generate new propositions while engaging with observation. From the perspective of IDV development, adapting abduction reasoning process can empower users to keep refining their proposition and addressing new information needs. It also enables developers to work upon their needs by refining the visualisation, such as including new data sources, modifying data models and adding appropriate interactive functions. It can be regarded as an interoperation between users and development for align the visualisation deliveries with information needs. Therefore, the specific steps of abductive reasoning process can be further demonstrated when developing the conceptual framework of IDV development.

4.5.3 Theoretical Proposition 3: IDV development enables Visualisation to serve for Knowledge Exploration

The third theoretical proposition is that IDV can serve users' knowledge exploration, and therefore when developing an IDV, a series of activities need to be deployed to help users bring their prior knowledge, refine their prior knowledge and generate new knowledge to guide the following actions. In the context of exploratory case study, the users confirmed that visualisation helps enrich their understanding of the financial and operational status of the selected charity, and further assists them to make decision whether they would like to support the selected charity and in what way they would like to support the charity, such as voluntary donation, working as a volunteers, recommend to friends and shopping in the charity shops e.g. "Since I found from the visualisation that the charity has a surplus last year, I might think more of support it via being a volunteer to help the seniors". In addition, users suggested that additional information (e.g. qualitative information) needs to be incorporated for them in order to build a holistic view of the selected charity's activities and contributions (e.g. "Not only the financial aspects, I would like to see more non-financial aspect of the charity activities, like we need focus more on the contributions the charity provide to the society".

The annotation functions and navigation in the IDV also help users build their knowledge and experience of interpreting the financial figures. Especially for the user without any knowledge and experience of reading financial figures, annotation can help them associate the figure with the description of facts e.g. "I think the annotation is very helpful for supporting me with financial knowledge. It enables me to understand the composition of charity spending and associate to the fact I might have seen before in my daily life". In addition, the users suggest capturing the analysis procedure from the professional analyst into a navigation path. Therefore, for other users, they might be able to follow the procedure to read the visualisation step by step, which might enable them to have a deep insight of datasets. It can also be regarded as an approach of knowledge sharing where the sense-making process can be shared among different users and might lead to a shared understanding.

In summary, based on the results generated from the exploratory case study, it is argued that IDV can serve knowledge exploration and, therefore, the IDV development can further incorporate the activities, such as consulting workshops to help users capture their prior knowledge and generate knowledges. Moreover, it is suggested the involvement of experts, through sharing navigation path or participating the consulting session, would help users explore and establish new knowledge based on the information revealed by IDV.

4.6 Summary

In the exploratory case study of charity report, a visualisation has been constructed in the scenario where users intend to understand and analyse the financial and operational status of charities and then to decide if it is worthy of supporting. The raw data for visualisation is collected from the Charity Commission API; initial users' information requirements for evaluating the quality and performance of charities are derived from the research of prior research of charity reporting practices (Dhanani and Connolly, 2012; Connolly and Hyndman, 2013; Hyndman and McConville, 2015, 2018) and can be further adjusted based on users participated in "think-aloud" session. A 4-step of linear data visualisation development approach has been utilised in this exploratory case study, including requirement articulation, data collection, visual representation programming and interaction design. Finally, based on the observation of users' action and analysis of users' feedback, the exploratory study further developed three theoretical propositions generated from the literature view, which can further inspire the construction of the conceptual framework in Chapter 5.

5. Conceptual Framework for Interactive Data Visualisation Development

Data visualisation can be regarded as a research field covering a wide range of themes, including visualisation theories, visual perception systems, visual design principle, and visualisation techniques and algorithms. However, it has been pinpointed by several research pieces that data visualisation lacks a well-developed body of theories as well as an integrated framework to incorporate the development process and techniques. Different software venue and whitepapers offer their own guideline for users to take use of their product, but the focuses of guidelines tend to be fragmented, rather than viewing the development of data visualisation as a whole process where visualisation techniques, users' demands and intentions, and contextual information all need to be involved. Therefore, the visualisation practitioners still encounter issues over how to incorporate users' requirements, intentions and contextual information into visualisation development for the purpose of enhancing their understanding, interpretation and sense-making of data.

Data visualization can be articulated as a process of communication with graphic means (Chen *et al.*, 2009; SAS, 2012; Wang *et al.*, 2016). Yi *et al.* (2007) and Nguyen *et al.* (2016) further develop the view of visualisation process by pinpointing that the development of data visualisation is a design process involving both technical and social aspects, which requires the aid of visualisation techniques for generating visualisation artefacts as well as the engagement of multiple stakeholders for addressing dynamic and complex demands. Therefore, the design process needs to be sustained by an logical reasoning approaches as a general guideline for acquiring the diverse demands and addressing the complex issues. Abduction is a reasoning process which can be associated with the design process, which aims to configure the most appropriate explanation toward the observed phenomena via proposing and refining the theoretical propositions and then contribute to the generation of new knowledge for guiding the following actions (March, 1984; Yu, 1994).

In addition, semiotic, as a theoretical ground of signs and signification, can help interpret the process where a sign as a carrier delivers information among different parties and guides the discovery of implicit and explicit factors impacting the efficacy of information transfer (Stamper, 2001; Liu and Li, 2015). By in-depth understanding the process and identifying the significant influencing factors, the producers can further work on improving the efficacy of communication, e.g. the right information can be communicated at the right time, by the right method and to the right people. Organisational semiotics, associating with the scope of business informatics, focuses on application and usefulness of signs in a business context, where the communication among individuals and business objects are driven by business purposes, serving for business objectives and influenced by organisational environments (Liu and Li, 2015). The specific components of OS theories include: semiosis for understanding the process of sign-signifying; semiotic ladder for identify potential influencing factors in multiple layers; norm-

based method for eliciting, analysing, documenting and communicating users' demands for interactive data visualization (IDV).

In this research, the important conceptual components of organizational semiotics will be discussed in order to lay a theoretical foundation of understanding the process of designing and interpreting data visualization. Based on the understanding of abduction process and organisational semiotics, the initial proposed theoretical propositions for interactive data visualisation (IDV) development can be addressed as follows. First, the development of interactive data visualisation is can be portrayed as an abductive reasoning process. Secondly, the development of interactive data visualisation is a norm-centric process where norm plays a key role to capture users' information demands, interpretation purposes and contextual pressures. Third, socio-technical view of IDV process can improve the users' understanding, interpretation and sense-making of data via continuously integrating users' requirements, purposes and contextual information.

Semiosis reveals the process of sense-making, where an individual understands a sign by interpreting it based on the link with a certain object (Stamper *et al.*, 2000). It is a universal mechanism which can be utilized for all sign-processing activities, which helps people to recognize the importance of creating and using signs. Interactive data visualization can be regarded as a typical sign-based communication, where visual representations act as signs to facilitate the communication between producers and readers.

The whole process of semiosis can be articulated into the following triangular model (Figure 5-1). The firstness is a sign or representation which is utilised as a sign vehicle linking to a secondness. The secondness is an object in actuality, which should be reflected by the sign in the firstness. However, the reflection might not be generic and spontaneous (see the dotted line), where readers cannot perfectly receive the information sent by producers without any deviation. Instead, the reflection will be impacted by the readers' interpretation based on prior knowledge, various purposes of interpretation and pressures from the organisational and social environment.

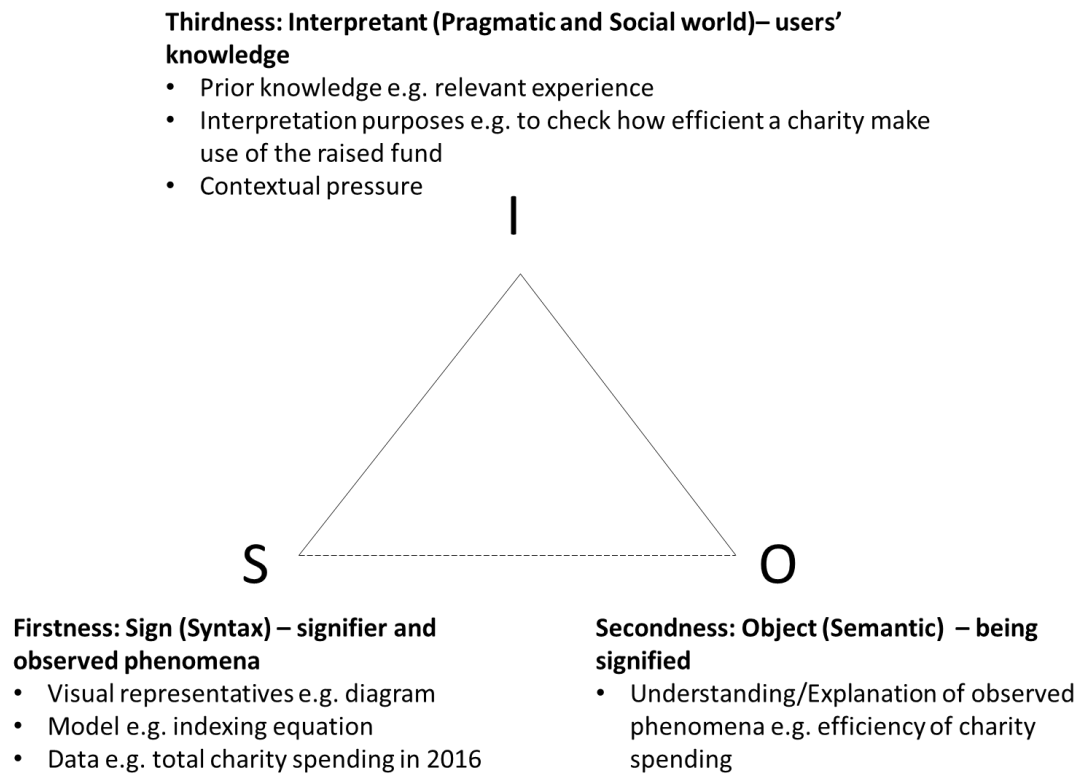


Figure 5-1 Semiosis in annotation of IDV research context

In the context of interactive data visualization, the meaning of three elements in semiosis framework can be further expended (Table 5-1):

Table 5-1 Elements in Semiosis in the Context of Visualization

Elements	Explanations in the context of visualization
The sign, which is considered as a signifier	Visual representations, including a diagram, chart, map and table
The object, which is considered as signified	Business actuality reflected or implied by the visual representations, e.g. market size; sales trend
The interpretant, which is considered as the effect of signs on readers' action (incl. reading, interpreting and behaving upon)	A process and result of interpreting signs and identifying their reflection based on readers' subjective elements e.g. knowledge, experience and perception of environmental pressures e.g. driven by the sales-oriented strategy applied in the corporate, managers will focus more on the information related to current and potential sales when viewing the visualization of market data

Even though the semiosis portrays a general framework for discovering the visualization process where readers make sense of visual representation, the interpretant can be explained further, especially identifying the factors influencing interpretant on both technical and social aspects. Interpretant has a broader scope than interpretation, which covers not only signifying a sign and identifying the meaning associating with the sign, but also involving readers' background knowledge, intentions and influences (incl. support and restrain) from social norms (Stamper, 1973). Thus, the semiotic ladder offers a

framework of taxonomy to categorise the various influencing factors towards interpretant to six levels. By understanding the concepts and characteristics of different levels, visualization producers can have an in-depth understanding in terms of the barriers which hinders readers from making sense of visual representations.

Stemmed by the theory of organisational semiotics which suggests understanding the barriers hindering the communication in the context of business through the lens of semiotics, Stamper (2001) suggests analysing the sign effect through six levels. When it comes to interactive data visualization, the lower three layers encourages producers to incorporate the Gestalt Law and pre-attentive attributes into visualization design, in order to assist human brain perceptive system to visually identify the patterns e.g. size, proximity and colours. On the upper three layers of the semiotic framework, the focus shifts from visual representation (signs) to interpretant of visual representation (sign effect). As implied from the comment 'featureless data is equivalent to noise', there is a big challenge on the cognition aspect of interactive data visualization: to enable users to capture the pattern of the dataset, to make sense of them based on their background knowledge, intentions and to cope with social pressure. Since this research mainly focuses on the sense-making aspect of interactive data visualization, the process framework will focus more on the key questions and norms on the upper three layers. However, the semiotic framework might have offered a comprehensive guideline (Table 5-2) for producers to recognise a series of social and technical factors which might affect sign effect – making sense of visual representations, but it does not offer a set of tangible methods to elicit and document the elements and come out a practical solution.

Table 5-2 Upper Three Levels of Semiotic Ladder

Factors	Explanation	In the context of interactive data visualization
Semantics	Meaning indicted by signs: the relationship between signs and objects	Do readers have a statistic or mathematic background to understand the algorithms behind?
Pragmatics	Intentions of readers to make sense of the dataset	What is the motivation(s) for readers to interpret the visual representations?
Social World	Context or environment where some factors might impact readers' focus and interpretation of visual representations	Based on what a reader can recognise, what are the major social and environmental factors which might impact on readers' opinions or focus?

Liu and Tan (2015) state the process for developing data visualization can be depicted as a shared semiosis where the visual representation is used as a carrier to facilitate the communication between the producers and readers. Not only does it focus on the artefact which carries the visual representation in the final stage, but it also focuses on the process where a reader interprets the visualization. Also, visualisation development can be depicted as norm centric activities, where a norm can be used a powerful tool to help producer aware and document readers' explicit and implicit demands in various levels of interpreting.

Thus, this research, inspired by the three principles from Liu and Tan (2015), is intended to construct a framework for producing data visualization, especially empowering readers to implement abductive

reasoning, guiding producers to place interactive functions based on norms and specifying the process of developing data visualization to steps.

The method of abduction supports human in developing or refining their knowledge by systematising the creativity and intuition into their logic reasoning process. The factors, such as prior knowledge and context, are also recognized as influenced to the people's understanding, instead of purely relying on what people can observe in the empirical study. Also, it emphasises that the aim of abduction is more than spotting the different of empirical study and prior understanding, but also includes understanding the new phenomenon and generate/reframe new understanding.

In this research the logic reasoning process of abduction can be depicted in Figure 5-2. It consists of six steps, including: 1) capturing and organising participants' prior knowledge for initial visualisation construction; 2) establishing the initial propositions based on the initial observation; 3) matching and updating information to the prior knowledge; 4) identifying the gaps; 5) addressing further questions; 6) refining/generating new knowledge for guiding the following actions.

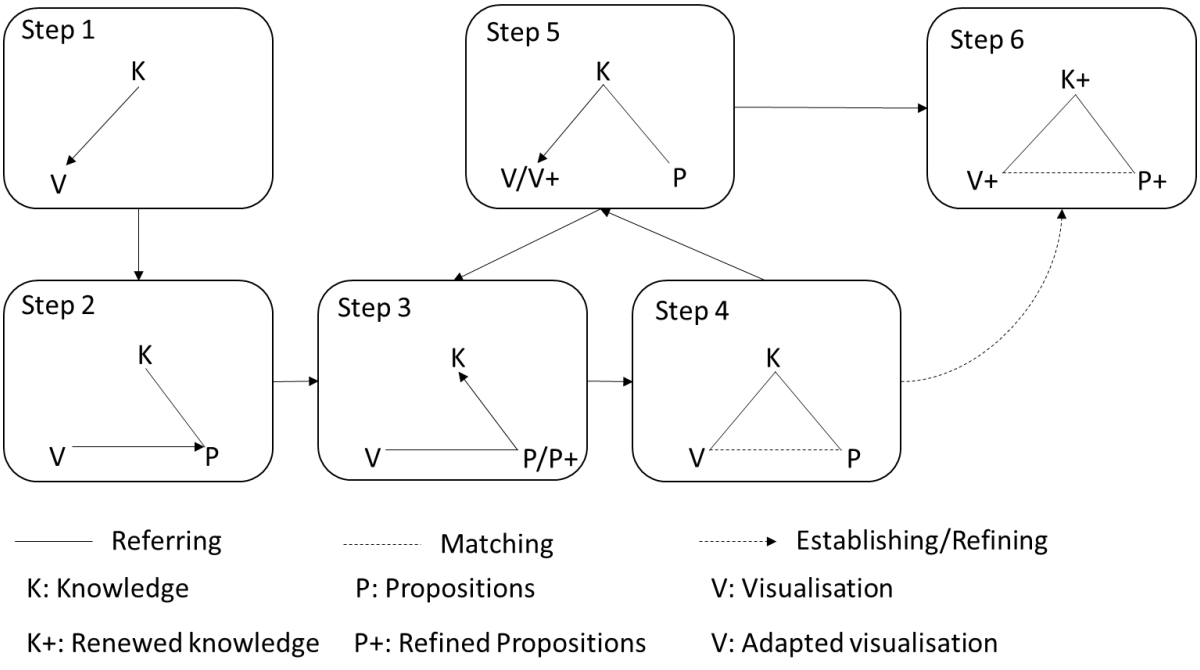


Figure 5-2 Abductive Process of Interactive Data Visualisation Development

The abduction process of IDV development contains a series of activities, such as inferring, matching and establishing/refining among different elements. The essential elements include knowledge (K), visual representations (V), and propositions (P). In addition, during the development process, participants can interact with visual representations (V) via address their ad-hoc demands, which further adapt visualisation (V+) to fulfil the diverse demands; with continuous observation of visual representations, the participant can refine their proposition (P+) which constitutes a more appropriate explanation toward the observed phenomenon. After several round of adapting (the recognition loop in

abduction process), observing and understanding the visual representations, the participate eventually renew their knowledge via making sense of data, which can guide their further actions. The six stages of the diagram will be further detailed in the sub-chapters 5.1-5.6. The content of this chapter is partially development from the publish work of Li and Liu (2018).

5.1Step One: Capturing and Organizing Readers' Prior Knowledge

At the start of the abduction process, it is necessary to let the users express their initial requirements based on their prior knowledge (K), which constitute preliminary inputs of users' demands for guiding the initial development of data visualisation (V). Different key stakeholders who will make use of data visualisation for data analysis need to be involved, as well as the developer team who can capture and organise the initial requirements and transfer them to the organised formats.

The developer team can identify the key stakeholders as users, and capture users' requirement based on their prior understanding. Users' persona can be established to analyse their background and basic demands with aid of Zachman's six dimensioned format (What, Who, Why, Where, When and How) (Table 5-3). Also, based on the framework of the semiotic ladder, readers' interpretant of signs can be impacted by their prior knowledge (semantic level), intentions (pragmatic level) and social context (social world level).

Table 5-3 User Persona based on Zachman 6 Dimensions and Semiotic Ladder

Initial version of users' persona based on Zachman 6 dimensions and semiotic ladder						
3-level of the semiotic framework	Semantic		Pragmatic		Social World	
Zachman's 6 dimensions	What	How	Who	Why	Where	When
Explanations in the context of data visualisation	What is the key question the users seek to address?	How would users prefer to explore the question?	The key stakeholders and its position on the context	The key motivations and purposes of data analysis	In what scenarios where will the data be analysed?	What are the triggers for the data analysis?

The information can be further made as a norm for guiding the design of interactive functions (Table 5-4). Based on the information obtained from the first step and dataset available on hand, the producer can draft the initial version of the data representation (V) and present it to the user.

Table 5-4 Norm Format

Whenever <context>	if <condition>	then <agent>	is <deontic operator>	to <action>

5.2 Step Two: Constructing The Initial Visualisation for provoking The Users' Initial Proposition

In the step two, a visual representation (V) is constructed based on the inputted norm from the step one for the purpose of offering an initial view of the data to the users. The construction mainly focuses on the three elements of visualisation development, including selecting a dataset, building a model and construct a visual representation. In other words, for each norm record, the developer team would map with the mechanisms of data selection, modelling building and visual representation construction. The selection of dataset indicates the developer team needs to incorporate the data sources associated to the "what" requirements inputted by users and to ensure that the dataset is able to contain the information (e.g. variables such as income) answer the associate questions. The building of model is associated with the "how" requirement, which reveals the approach that users prefer to explore the data (e.g. time scale like annuity or quarter; calculation like average or sum). The construction of visual representation is based on the following three sub-activities in Table 5-5.

Table 5-5 Initial Sub-activities and techniques of IDV development

For each norm …	
Sub-activities	Techniques and methods of developing IDV
Collecting data	Incorporating the appropriate data sources based on initial requests, including data content, metadata and data properties
Establishing model	Establishing initial data processing methods and algorithms based on the initial requests, e.g. changing from singular variable to multiple variables, and to indexing techniques
Selecting visual representation	Selecting the initial group of visual representations based on the requests, including chart types, layout, colour code and applied design principles

After the construction of visual representations, the user can then have an initial view of the visual representation (V) for generating the initial propositions (P) about general data pattern with the aid of prior knowledge (K). The development of visual representation in this stage is based on the initial input of users' demand and data availability. The main purpose is to enable users to have an overview of data with the help of prior knowledge and to further address more questions related to the data.

A think-aloud session needs to be scheduled between users and the developer team during the initial view of data visualisation for the purposes of provoking and documenting the users' initial propositions. Users can make comments or answer interview questions while viewing and interacting with the initial data visualisation. In particular, when the users found the data or data patterns that they cannot instantly understand based on the initial data visualisation, the information needs to be captured to guide the further development of data visualisation. Thus, the session can be conducted via semi-structured interview to encourage users to talk through their immediate understanding based on initial visual representation and prior knowledge. The key questions mainly focus on the following three aspects: 1)

overview of data visualisation; 2) highlighted findings based of data patterns; 3) main puzzled spotted in the initial data visualisation. The specific address of interview questions and probs (for directing the expression of users' feedbacks) are described in Table 5-6.

Table 5-6 Sample questions for user feedback (stage 2)

Key aspects	Sample questions and probs
Overview	What is your general understanding based on the initial data visualisation? Prob: Based on the visualisation, I am aware … (variables and value)
Highlighted findings	What are your key findings based on the initial data visualisation? Prob: It associate to my question …. It reveals that ….
Spotted puzzles	What are the further questions you would like to address? Prob. It is not clear that …. I therefore would like to further explore …

5.3 Step Three: Matching and Updating Propositions to the Prior Knowledge

In step two, an initial view of visual representations and think-aloud session can help users to generate the initial propositions. Then, in step three, a consulting workshop is scheduled with the involvement of users, developer team and experts to further understand the users' proposition, including both highlighted findings and spotted puzzles. It can help match the propositions with prior knowledge for interpretation, as well as updating new proposition to the users' knowledge.

Users' propositions are generated from the basic understanding of initial visual representation. With the involvement of experts, the users' proposition can be further interpreted in a business sense, which reveals the business indications of a certain data pattern e.g. its potential impacts on the income or profitability of a business. Furthermore, the business interpretation can be associated with the knowledge for the purpose of configuring suggestions for the following actions or addressing the further questions. As is shown in Table 5-7, the highlighted findings can be interpreted with incorporation of experts' domain knowledge to analyse its business meaning. It can be further associated with certain knowledge to generate actionable guidance where a certain action can be taken in a certain context. For the spotted puzzles, the proposition can be further detailed with help of experts' knowledge to reveal what specific information still needs be incorporated into the visualisation for the exploration of dataset. It also can be associated with users' prior knowledge and experts' experience, and further generates more requirements for the data visualisation development in the following step.

Table 5-7 Consulting Session Outputs

Vis Item ID	Propositions	Business Interpretation	Associated knowledge
Vis Item ID	Highlighted findings	What is the indication which can help with your business?	Which part of prior knowledge/experience can it associate with?
Vis Item ID	Spotted puzzles	What is the confusion or unclear information in your business context?	Which part of prior knowledge/experience can it use for explanation?

5.4 Step Four: Identifying the Cognition Gaps

Step four can be understood as a check point, which checks the extent to which users have already obtained the information to fulfil their demands. It also helps with identifying the gaps where further information might need to be revealed in the data visualisation. There are two possible routes. In the first route, the user might have already obtained sufficient information from through viewing the initial data visualization. They might directly find a good answer from the initial data presentation (resolve the puzzle) and then they can connect to the step 6, such as confirming their prior knowledge or already adding more new knowledge. In the other route, the users might find gaps between the observed visual representations and their established propositions where the prior knowledge cannot offer an appropriate explanation (remain to be a puzzle). The users can then configure new requests for incorporating further information in the visualisation, which articulated in a norm format for guiding the visualisation development in the following steps.

A consulting session can be scheduled among users, experts and development team. Developer teams can present the data visualisation that users have engaged with in the previous step as well as the documented propositions. Based on the visual representations and propositions, users can revisit the initial requirements proposed in step 1 and evaluate to what extent where the data visualisation has supplied sufficient information. Experts then can further help users with drawing conclusions based on the current findings and configuring the actional suggestions. Alternatively, the users can further point out the "puzzles" they encountered when viewing the visual representations. The experts can help with explaining the puzzles based on their knowledge and experience, as well as help users address more requirements/questions that they would like to know via data visualisation.

Based on the categories of "highlighted findings" or "spotted puzzles", experts' input can be further added into the table for documentation. For the highlighted findings, the experts can further add the "conclusions" for summarising the findings and "suggestions" for guiding the following actions (Table 5-8).

Table 5-8 Conclusion documentation

Conclusion ID	Conclusion	Suggestions	Associated "highlighted findings"
Conclusion ID	Based on the highlighted findings, conclusion can be drawn with the association of business interpretation	Based on the conclusions, what action can be taken in the business context?	"Highlighted finding" tags for tracking back

For the spotted puzzles, the experts can further add explanations for pinpointing the embedded causes and encourage users to further express more new questions in "further request" (Table 5-9).

Table 5-9 New Request Documentation

Request ID	Further request	Embedded reasons	Associated "spotted puzzles"
Request tag	For resolving the puzzle, what is the further request which needs to be addressed when adjusting the data visualisation?	What are the embedded reasons for addressing the request? E.g. purposes	"Spotted puzzle" tags for tracking back

For the purposes of inputting the users' request into the IDV development in the following steps, the users' requests in the table can be transferred into the norm format. Moreover, based on the diverse focuses, the norms can be put into the following categories which can be associated with the different parts of IDV development (Table 5-10). The incorporation of norms can help transform the users demands from the natural language to a structured express where the information of context, intention, and semantic meaning can be clearly identified. Then 5 categories of norms can assist map norm with sub-activities during the IDV development, especially in the step five where, for example, perceptual norm focus on viewing the sign for acquiring information and therefore it can aid with the selection of visual representations. The detailed level the mapping between norm categories and sub-activities can be found in Table 5-11.

Table 5-10 Categories of Norms

Norms	Explanation in the context of IDV development
Perceptual norms	Help users perceive the sign (visual representations) e.g. charts, layouts and colour codes
Cognitive norms	Enable users to incorporate knowledge and experience for interpretation
Evaluative norms	Support users to discover reasons why users input the purposes and objectives
Behavioural norms	Govern user behaviours during the interaction
Denotative norms	Direct the selection and organisation of signs for signifying depending on the context

5.5 Step Five: Further Constructing Data Visualisation based on Further Requests

In step four, the recognition gaps can be identified with help of experts and the gaps can be further addressed in the norm format for guiding the further development of data visualisation. Once readers find the information revealed from the initial data visualization is different from their prior understanding, the readers might enter into an iterative process (Figure 5-3: Step 5 – Step 3 – Step 4), where they can address further questions based on their information demands. In other words, they will compare what they have seen from the visualization with what users have understood from the prior

experience and identify the differences, from where they can further address new questions into data visualization by its interactive functions.

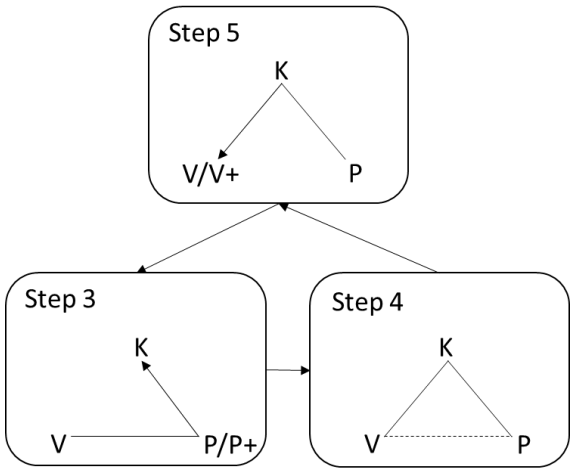


Figure 5-3 Recognition Loop within IDV Development Process

In step five, the developer team can further develop the data visualisation based on the users' further requests. The new requests in the norm format can be mapped to the different IDV development sub-activities (Table 5-11), and then be associate with the different techniques and methods for the development in a detailed level.

Table 5-11 Sub-activities for IDV Development

Sub-activities	Related techniques and methods	Associated norm categories
Collecting data	Incorporating other data sources based on the new requests, including data content, metadata and data properties	Perceptual and cognitive
Establishing model	Upgrading data processing methods and algorithms based on new requests, e.g. changing from singular variable to multiple variables, and to indexing techniques	Perceptual and cognitive
Selecting visual representation	Adjusting visual representations based on new requests, including chart types, layout, colour code and applied design principles	Perceptual and cognitive
Designing interaction	Enabling "what-if" analysis – modify the parameters then observe the changes of results e.g. filtering, benchmarking and drill-down or roll-up	Behavioural and evaluative
Setting navigation	Setting a sequence of viewing different visual representations and connections among different visual entities	Behavioural and evaluative
Constructing story line	With the incorporation of expert knowledge, constructing a mainstream story line to reveal and interpret the major patterns of dataset, following the procedure of "context-content-conclusions"	Denotative

After the adjustment of data visualisation, the users can be re-engaged for viewing and interacting with the visual representations. It indicates that step 3 can be retriggered for generating new propositions based on the adjusted data visualisation. It then can be followed with a think-aloud session for

documenting the refined proposition and its associated business interpretation and prior knowledge. The consulting session can be scheduled again for involving the experts into the consultation, which can further take away appropriate conclusions and actionable advices. It can help with identifying further requests that would be used as new input to the further adjustment of data visualisation.

Different from the linear process appeared in the prior data visualisation development process, "recognition loop" embedded in the abduction process has been applied in the IDV development process (demonstrated in steps 3, 4 and 5). Within the loop, the users can interact with the data visualisation in an iterative pattern, where they can generate and refine the propositions based on continuous observation of data visualisation and address new requests to the developer team for fulfilling their recognition gaps. At the same time, for developer teams, they can identify different layers of users' demands during continuous engagement, including the supplementary information for understanding, the purposes of interpretation and contextual information for sense-making. It would eventually support the final product of data visualisation able to fulfil the semantic, pragmatic and social demands of users.

5.6 Step Six: Refining/generating New Knowledge for Guiding The Following Actions

Step 6 can be launched when users find no significant recognition gaps during the consulting session in step 4 and no more new requests need to be inputted into the data visualisation. It means that they believe that the data visualisation has already supplied enough information for proposition generation and knowledge renewal. As a result, with the help of adjusted visualisation (V+), a series of refined propositions (P+) have been generated for understanding the data. Therefore, in step 6, a summary session can be scheduled in step 6 with the engagement of users, developer team and experts for the purpose of finally configuring new knowledge (K+) to guide the following actions.

During the summary session, the developer team can finalise the data visualisation development based on the current documents of norms as well as their associated sub-activity records. Users can then further configure the conclusions from the analysis with the aid of final data visualisation and further generate new hypothesis which can be examined in following practices. The inputs of experts can be involved for generating suggestions for the further actions, e.g. the suggestion to entry a selected market; they can also advise the approaches and methods for users to examine their new hypothesises. Eventually, all key information (Table 5-12 and Table 5-13) generated from the summary session can be added in the tag of "conclusions" of IDV, which can enable users to take IDV final product away for further usages, such as continuing to use as analytic tools or to communicate with other relevant stakeholders in terms of key conclusions and hypothesises based on the data visualisation.

Table 5-12 Conclusion Documentation in Step 6

Tag	Conclusions	Actionable suggestions

Conclusion tag	The content of conclusion configured based on the IDV product	With the help of experts' knowledge and experience, the suggestions are that user can take away for implementation in their business context

Table 5-13 New Hypotheses Documentation in Step 6

Tag	New hypotheses	Further examinations
Hypothesis tag	Based on the conclusions, new hypotheses that users would like to further examine in the following actions to justify the conclusions from different perspectives	Other than the current IDV product, experts might suggest other approaches to gather data to examine the hypotheses

5.7 Summary

This chapter constructs a revolutionary view on interactive data visualisation development, consisting of six steps with detailed description of the activities and methods. The abductive reasoning approach has been embedded in the process for enabling users to keep refining their propositions and addressing their demands during the process of continuous development (during the development loop). It also enables developers to continuously understand users' demands and incorporate them into the development of IDV. Therefore, the abduction process sufficiently incorporates the inputs from users and experts, such their information demands, interpretation purposes and contextual pressure, during the process of IDV development. Echoing the focal issues in Chapter 1, the IDV deliverable produced at the end of process would be able to fulfil the users' demands on the multiple layers on the semiotic ladders, including semantic, pragmatic and social levels.

6. Case Study: Global Market Selection Intelligence with Abductive Framework of IDV Development

This chapter illustrates the application of Abductive **F**ramework for **In**teractive Data **Vi**sualisation **D**evelopment (FINVID) in the case study of market intelligence development. FINVID is developed based on the theoretical propositions elaborated in Chapter 2 as well as the results of observation and user feedbacks generated in the exploratory case study in Chapter 5. FINVID includes six steps (Figure 5-2): 1) capturing and organising participants' prior knowledge for initial visualisation construction; 2) establishing the initial propositions based on the initial observation; 3) matching and updating information to the prior knowledge; 4) identifying the gaps; 5) addressing further questions; 6) refining/generating new knowledge for guiding the following actions. Each step and the corresponding application and techniques are illustrated in the sub-chapters.

In the illustrative case study, the illustration of FINVID is based on a case study of developing an IDV-based market intelligence tool for Company C, which possesses an energy drink brand and was planning for internationalisation during the case study period. IDV plays an essential role in the case study for helping different users make sense of the datasets of global market research. Based on the diagram of research design (Figure 3-2), the illustrative study corresponds to phrase two for illustrating and further developing FINVID in a working scenario, followed by the evaluation of FINVID based on the users and experts' review. Inspired by Fischer et al. (2012), the evaluation in the design science research can be conducted based on four aspects, including validity, utility, generality and innovativeness. The validity aspect evaluates if FINVID as well as its produced artefacts can help with users' understanding, interpretation and sense-making; the utility aspect evaluates if FINVID as well as the visualisation work is easy to use, performing well in terms of helping users' with their information demands, and the appropriateness of achieving the users' purposes; the generalisability aspect evaluates if FINVID can be reused in a different context and serve a different purpose; the innovativeness aspect evaluates if FINVID can deliver a novel contribution to research and practice. Following the design science research process diagram, the validation of FINVID is implemented based on expert feedback and evaluation. It involves the information system and marketing experts as well as the key users in the illustrative case study for assessing the four aspects of validity, utility, generalisability and innovativeness of FINVID. The results of validation are demonstrated and discussed in Chapter 7.

6.1 Background to the Case Study

The case study is based on a research project requested by Company C, an energy drink company from Thailand developing an IDV based on a scenario of market intelligence. Company C was established in the 2000s and possesses a well-established energy drink brand in Thailand which was listed as Top 3 Thai energy drink brand between 2012 and 2015, right after the top 1 energy drink brand "Red Bull".

Boosted by its strong growth and market share in the Thai market, Company C was thinking of internationalisation – growing to be an international energy drink company and to extend the sales of its energy drink products to the global market. Therefore, Company C was going to select a series of national market as a start to launch their internationalisation strategy. However, the executive team in the Company C encountered the following difficulties when analysing the dataset about the global energy drink market. Firstly, although they purchased the data from the leading market consulting companies, such as Canedean and Euromonitor, they found very difficult to understand a huge volume of data and make sense of them to guide the following actions. Secondly, although they have access to a wide range of analytics and visualisation software which offers the analytic and visualisation capacities, they found it is hard to enable the data analysis results to respond to the information demands due to the lack of guidelines and methods to elicit and manage users' requirements. Thirdly, they do not have an efficient method for exploring new knowledge based on the analytic results of datasets. They found it very hard to involve experts and other stakeholders during the analysis process, which makes the results hard to communicate and be comprehensible to others.

In the research project, the application of FINVID is employed to facilitate the development of IDV in the scenario of market intelligence where the executive team of company C can make sense of the datasets about global energy drink market and take actions to further develop its internationalisation strategy. Kotler *et al.* (2019) portrays the market intelligence (MI) as a procedure where managers can retrieve the information about the changing market environment. Rodrigues and Pinho (2012) describe MI as an information integrator of internal and external environment information for developing a rational decision in terms of market selection, competitor matching and strategy design. Auh and Menguc (2005) depicts MI, as a connector between top management team and information system, needs to capable of answering questions from the top-level managers. Venter and Rensburg (2014) have proposed an integrated framework of MI, which highlights the input of internal and external data, integrated data storage, ETL process, data integration among people, process and technology, visualisation and communication. They also highlights that the visualisation in MI reveals the value of intelligence in managerial decision-making processes. The challenges of developing visualisation in the scenario of MI are also discussed in previous research. Hedin, Hirvensalo and Vaarnas (2011) states that increasing accessibility of market-related data and advancement of software analytical capacity does not necessary facilitate the development intelligence. An insufficient understanding of users' information demands and interpretation context constitute the situation of "data rich but information poor", which in other words prevents delivery of the right information in the right context. It echoes the "interpretant gap" (Liu and Tan, 2015) where insufficient communication of user's requirements as well as prior knowledge related to the interpretation would weaken the outcome of sense-making in the scenario of visualisation. In addition, Luu (2014) claim that, other than the MI techniques, adequate actions such as incorporating experts' knowledge and experience, or interactive functions to respond to

the users' requests, need to be further involved in order to construct MI as a strategic tool. It echoes the statement from Cacciolatti and Fearne (2013) that the construction of MI requires the interoperation and continuous engagement of different stakeholders, instead of solely relying on the techniques and software.

Therefore, FINVID is applied to facilitate the development of IDV in the scenario of MI development for Company C to analyse the data of global energy drink market. It also helps to resolve the users' difficulties during the IDV development, including managing/addressing users' requests, mapping techniques to users' sense-making, facilitating knowledge exploration. Based on users' feedback, three propositions are also further refined: 1) IDV development as a norm-centric process; 2) IDV development as an abductive reasoning process; and 3) IDV facilitating knowledge exploration. In FINVID, the abductive framework helped to elicit users' information requirements (semantic), different intentions of using visualisation (pragmatic) and pressures from organisational environment (social world). In particular, the iteration for continuously capturing user feedback enables products to recognise the changing demands and refined understanding, which can facilitate the sense-making of dataset and further assist decision-making.

6.2 The Overview of FINVID

The development of FINVID is based on the theoretical propositions refined in Chapter 5. The first proposition is that data visualisation can be understood as a norm-centric process. A norm plays a central role in articulating user demands and leading the development of IDV in order to facilitate users' understanding, interpretation and sense-making of datasets. The second proposition is that IDV development process can be portrayed as an abductive reasoning process, where users can observe the phenomenon and generate the initial propositions with their prior knowledge and then continuously refine the proposition while engaging with iterative observation. IDV development is not an "one-off" process; it requires iterative engagement and the input of users for fulfilling their diverse and developing demands. The third proposition is that IDV can serve for users' knowledge exploration, and therefore when developing an IDV, a series of activities (e.g. think-aloud and consulting sessions) need to be deployed to help users bring their prior knowledge, refining their prior knowledge and generate new knowledge to guide the following actions.

FINVID consists of six steps, which are demonstrated in Figure 6-1 Abductive Reasoning Process of FINVID. 1) capturing and organising participants' prior knowledge for initial visualisation construction; 2) establishing the initial propositions based on the initial observation. After the first two steps, in order to further discover users' demands, consulting sessions would be scheduled to incorporate the inputs from the relevant experts, which includes: 3) matching and updating information to the prior knowledge; 4) identifying the gaps; and 5) address further questions. Step 3-5 also constitutes a recognition loop as

an important component of abductive reasoning process where the IDV can be continuously adapted to users' changing demands while they address their additional information demands based on their recognition gaps. When the users have obtained sufficient information for renewing their knowledge and provoking the following actions, step 6 is triggered, which refers to refining/generating new knowledge for guiding the following actions. The aforementioned process demonstrates the iterative natural of abductive reasoning process for developing an IDV to fulfil users' demands of understanding, interpreting and making sense of datasets.

To be specific, the overall process of FINVID follows the abductive reasoning process inspired by (Tan, Abdaless and Liu, 2018). The techniques mapped into each step are briefly explained as follows. Based on Figure 6-1, step 1 aims to capture users' initial requirements as well as the associated prior knowledge which might impact upon their demands and interpretation. It includes identifying key stakeholder related to IDV development via stakeholder onion (Liu, 2000), establishing user persona via Zachman's six dimensions (Zachman, 1997), and articulating the requirements to the norm specification (Wright, 1977; Liu and Ong, 1999). Step 2 aims to establish an initial version of IDV in order to lead users' initial feedbacks as well as further potential requests. An initial version of IDV can be developed based on the four basic sub-activities: collecting data, establishing model, selecting visual representation and designing interaction. It is followed by a think-aloud session method (Lee *et al.*, 2016), where users can make real-time feedback while being engaged with the IDV. It helps the developers understand the rationales behind users' actions during their participation. Step 3 aims to generate users' propositions based on the interaction with IDV. All propositions can be categorised as "highlighted findings" and "spotted puzzles". With the inputs of experts' knowledge and experience, business interpretation (e.g. what does it mean or indicate in the business context) and association with prior knowledge can be further established. Step 4 aims to help users identify the key conclusions and key recognition gaps for furthering IDV development. A further consulting session would be scheduled with involvement of experts. During the session, the conclusions can be generated based on the "highlighted findings" and the further requests can be generated based on the "spotted puzzles", which can further assist the development of IDV for fulfilling users' demands. All newly generated requests are mapped into the five categories of norms (perceptual, cognitive, evaluative, behavioural and denotative norms) to further lead the refinement of IDV. Step 5 aims to further develop IDV based on the new requests generated in step 4. Five categories of norms are mapped into seven categories of sub-activities of IDV development: collecting data, establishing model, selecting visual representation, designing interaction, setting navigation and constructing story line. The refined IDV is inputted back to step 3, which starts the recognition loop (step 3-5) again to further capture users' findings and puzzles. Once the users feel they have obtained sufficient information to guide the following actions, step 6 is triggered. Step 6 aims to finalise the IDV based on the captured users' requirements, which can help users articulate their conclusions as well as a new hypothesis. By possessing the final product of IDV,

they can review the key analysis results based on IDV, where they have renewed and refined the prior knowledge. It can also help them review the whole process of generating the results when they share or represent the conclusions to other relevant stakeholders.

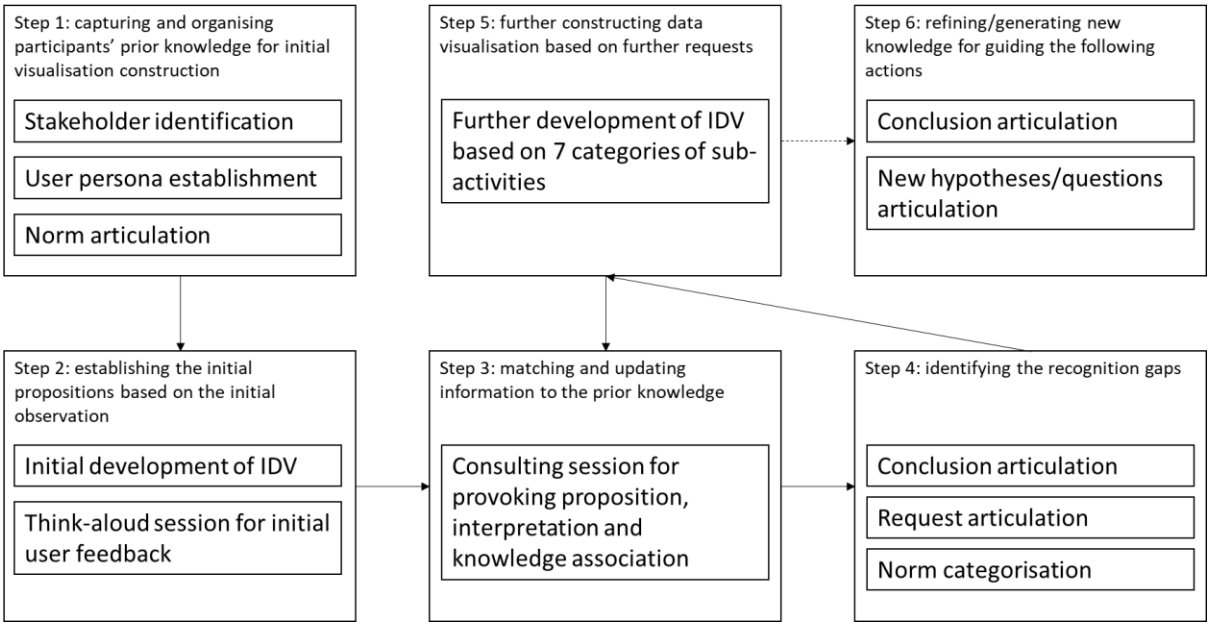


Figure 6-1 Abductive Reasoning Process of FINVID

6.3 Step 1: Capturing and Organising Participants' Prior Knowledge for Initial Visualisation Construction

The first step aims to collect the users' initial requirements and prior knowledge as initial inputs for IDV development. Referring to Liu and Tan (2015), other users' information demands (what they would like to know), their interpretation purposes (why they would like to know) and contextual factors (which positions they are in or which role they are playing) would also have significant impacts on their understanding, interpretation and sense-making of data. Therefore, in step 1, it is necessary to clarify the key stakeholders who address the requests to IDV, to collect their background information via making persona as well as eliciting their initial requirements.

In the scenario of the illustrative case study, the specification activities in step 1 were implemented in the initial rounds of project meeting. Based on the framework of stakeholder onion, the key stakeholders and their roles were identified (sub-chapter 6.3.1). Inspired by Zachman 6-dimensions as well as the semiotic ladder, the key background information related to each stakeholder can be documented with the categories of semantic, pragmatic and social layer (sub-chapter 6.3.2). Finally, the initial requirements revealed during the project meeting were documented in a norm format with specification of five key elements, which works as key inputs for developing the initial version of IDV (sub-chapter 6.3.3).

6.3.1 Stakeholder Identification

Stakeholder identification was implemented in the initial project meeting, to identify the key stakeholders in the research context who generate main impacts on the IDV development, such as addressing requests, inputting knowledge and information and contributing development capacities. The roles and functions of each stakeholders are also specified for the purpose of revealing the direct or indirect association between them and IDV development. For examples, the role of stakeholders in the project context might provide them with a specific focus on data interpretation and a motive to address a specific information need. The stakeholder onion framework from Liu et al. (2016) is applied in the scenario where the framework guides the researcher to manage stakeholder by categories, such as actor, client, provider, facilitator, governing body and bystander (Figure 6-2).

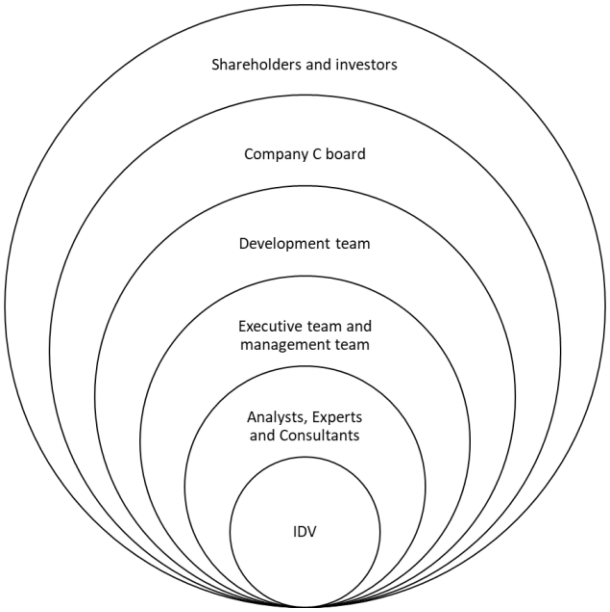


Figure 6-2 Stakeholder Onion in IDV context

Based on the scenario of illustrative case study, the key stakeholders, their roles and impacts are analysed in Table 6-1. It can help the development team to understand the key person involved in the IDV development process and what key input as well as impacts they might contribute to IDV development. Following the iterative pattern of abductive reasoning process, the further information of each stakeholder, like their specific information needs to be addressed in the IDV, can be discovered further in the following steps (see Table 6-1).

Table 6-1 Identification of key stakeholders in IDV development

Stakeholders	Roles	Impacts
Executive_1	Executive director	Main decision-maker of internationalisation strategy. Focusing long-term development as well as growth potential of the whole company. Interested in identifying and developing investment opportunities.

		Able to supply the information of internal resources and capacities.
Marketing_1	Marketing director	Focusing on market analysis and selection. Interested in analysing the market status and potential market growth. Be able to supply the information of interested criteria of market performance evaluation as well as benchmarks based on experience.
Finance_1	Finance director	Focusing on analysing financial performance, such as sales and profit in each market. Interested in analysing the potential income and risks of entering a target market. Be able to supply the information of interested approaches to measuring financial performance as well as criteria or thresholder of selected eligible market.
Operation_1	Operation manager	Focusing on monitoring the changing trends of market Interested in the process of developing, maintaining and utilising the IDV product. Able to supply the information of preferred ways of using and maintaining IDV.
Project_1	Project consultant	Focusing on requirement management and results communication. Interested in the presentation, interaction of IDV, since it will be used to communicate the results with the board members and other shareholders.
Analyst_1	Data analyst	Focusing on data collection and modelling. Supporting with data modelling and statistical analysis
IS_Expert_1	IS expert	Focusing on the IDV development process and usability. Interested in the alignment between IDV development and the fulfilment of users' information needs.
Marketing_Expert_1	Marketing expert	Focusing on market analysis. Interested in knowledge exploration via IDV.
Developer_1	IDV developer	Focusing on resolving the technical issues, such as underlying software architecture, data source connection and Tableau development.

In the initial stage, Executive_1, Marketing_1, Finance_1 are the main users of IDV who input the mainstream requirements as well as playing the main roles of using IDV for the facilitating of their decision-making. Therefore, at the initial stage, the user persona and requirement analysis mainly focus on them.

6.3.2 User Persona Establishment

After identifying the key stakeholders in the project scenario, the associated information of each stakeholder is managed by establishing user personas. Persona is a method to understand users' needs with the aid of background information. It incorporates the information of goals, roles, expected engagement and important assumptions generated from the background as well as prior experience. Based on the abductive reasoning process, the persona can be utilised at the initial stage to capture the background information of each participant in order to understand the initial requirements, and then the relevant information and requirements can be updated during the further participation.

Inspired by semiotic ladder from Liu (2000), the users' requirements and background information can be sorted into three categories, including the semantic layer which associates with the understanding of meaning carried by signs, the pragmatic layer which relates to the purpose of interpreting signs, and the social layer which refers to the contextual factors impacting upon the sense-making of signs. In addition, in order to structuralise the information of requirements and user background, Zachman's 6 dimensions (Table 6-2) are employed in the persona, including what (key questions they seek to answer), how (the approach they explore the questions), who (roles and relevant background), why (key motivations and purpose of interpretation), where (scenario of data sense-making) and when (the triggers of data analysis).

Table 6-2 Template for initial version of user persona

Initial version of users' persona based on Zachman 6 dimensions and semiotic ladder						
3-level of the semiotic framework	Semantic		Pragmatic		Social World	
Zachman's 6 dimensions	What	How	Who	Why	Where	When

In this initial stage of IDV development, Executive_1, Marketing_1 and Finance_1 are the key stakeholders mainly involved in the process. Therefore, the initial user personas were made based on the discussion held in the initial project meeting. Based on the content captured during the meeting, the examples of uses persona are presented in Table 6-3, Table 6-4 and Table 6-5.

Table 6-3 User Persona (Executive_1)

Stakeholder tag	Executive_1
Version no.	v1.0
Who	Role: Executive director. Background: MBA with fundamental statistical knowledge. Focus: long-term development, investment opportunities.
What	Selecting a series of markets for initialising international development. Comparing different market based on market size, which reveals the current market status. Comparing the average growth rate of market value to reveal its growth potential.
Why	To identify the opportunities of entering international markets; and to reveal opportunities for further development and investment.
How	Comparative view among different markets with bar chart; benchmark with average.
Where	Initial stage of internationalisation strategy – to present an attractive plan to the board as well as other investors for the approval of internationalisation and further investment. Coping with the pressures from the board and shareholders – seeking for new market and new opportunities.
When	In the board meeting as well as shareholder gathering. When presenting the market analysis results. When responding to the audiences' questions.

Table 6-4 User Persona (Marketing_1)

Stakeholder tag	Marketing_1
Version no.	v1.0

Who	Role: Marketing director. Background: Business with little statistical background. Focus: current market status, competition situation, consumer behaviours (e.g. buying and perception of brand value), market positioning.
What	Evaluate the market attractiveness based on the market value, customer patterns and growth.
Why	To identify the opportunities of entering international markets.
How	Comparative view among different markets with bar chart; benchmark with average. Only "off-premise sales" included due to the market focus of company C.
Where	Initial stage of internationalisation strategy – support executive directors to obtain the approval of internationalisation plan from the board.
When	In the executive team meeting (report to the executive director). In the management team meeting (market and sales team).

Table 6-5 User Persona (Finance_1)

Stakeholder tag	Finance_1
Version no.	v1.0
Who	Role: Finance director. Background: Accounting and Finance with experience of quantitative analysis. Focus: market value, unit price (per litre), prediction of market value growth and potential costs of entering a new market.
What	Measure the market values and potential growth. Measure the potential risks associated to entering a new market.
Why	To identify the opportunities of entering international markets. To predict the amount of potential income as well as the potential growth in the long-term. To identify the risks which might increase operating costs.
How	Comparative view among different markets with bar chart; with specific benchmarks as follows: All measures in monetary format (USD). Filtering the market with less than 100 million USD of annual sales.
Where	Initial stage of internationalisation strategy – support executive directors to obtain the approval of internationalisation plan from the board.
When	In the executive team meeting (report to the executive director). In the management team meeting (market and sales team).

6.3.3 Norm Articulation

Based on the user persona established in sub-chapter 6.3.2, the following common requirements can be identified: 1) market size analysis based on annual total sales; 2) market value analysis based on annual total value in USD; 3) market growth of market size between 2013 and 2015. Incorporated with the background information from user persona, the users' requirements can be further documented in the norm format (context, condition, agent, deontic operator and action).

The norms in Table 6-6 are further inputted into the step 2 for guiding the initial development of IDV, including collecting data, establishing models, selecting visual representations and designing interactions.

Table 6-6 Norm specification (initial loop)

Norm tag	Whenever <context>	if <condition>	then <agent>	is <deontic operator>	to <action>

mrk_size_1-1	Analysis of market attractiveness based on sales information	The market sales information is requested	Users (executive director)	Permitted	Extract “total sales” from Canendean data source
mrk_size_1-2	Analysis of market attractiveness based on sales information	The market sales information is requested	Users (executive director)	Permitted	Compare different market based on amount of “total sales” marked as “market size”
Mrk_size_1-3	Analysis of market attractiveness based on sales information	The market sales information is requested	Users (executive director)	Permitted	Present with comparison view with horizontal bar chart
mrk_value_1-1	Analysis of market attractiveness based on value information	The market value information is requested	Users (Finance director; Marketing director)	Permitted	Extract “total value in USD” from Canendean data source
mrk_value_1-2	Analysis of market attractiveness based on value information	The market value information is requested	Users (Finance director; Market director)	Permitted	Compare different markets based on amount of “total value in USD” market as “Market value (USD)”
Mrk_value_1-3	Analysis of market attractiveness based on value information	The market value information is requested	Users (Finance director; marketing director)	Permitted	Filter the market(s) with less than 100 million USD of annual sales
mrk_value_1-4	Analysis of market attractiveness based on value information	The market value information is requested	Users (Finance director; marketing director)	Permitted	Present with comparison view with horizontal bar chart
Mrk_growth_1-1	Analysis of market attractiveness based on growth information	The market growth information is requested	Users (executive director; marketing director)	Permitted	Extract “growth rate of total sales” from Canendean data source
Mrk_growth_1-2	Analysis of market attractiveness based on growth information	The market growth information is requested	Users (executive director; marketing director)	Permitted	Calculate the average “growth rate of total sales” between 2013 and 2015
Mrk_growth_1-3	Analysis of market attractiveness based on growth information	The market growth information is requested	Users (executive director; marketing director)	Permitted	Present with comparison view with horizontal bar chart
Control_1-1	Market attractiveness analysis	IDV interface is initialised	Users	Permitted	Select one or more national

					markets based on name

6.4 Step 2: Constructing the Initial Visualisation for Provoking The Users' Initial Proposition

Based on the norms articulated in sub-chapter 6.3.3, the collected user requirements can be inputted to the initial development of IDV. Compared with the plain description of user requirements, norm specification help with specifying the context, condition and content of visualised datasets. It can help analysts to map the norms into the sub-activities of IDV development. In step 2, an initial version of IDV was developed based on the initial user requirements for addressing their initial information needs and further understand users' demands based on their feedback during the think-aloud session. In sub-chapter 6.4.1, 3-tier application architecture reveals the technical perspective of IDV, including its data source, application and interface. In addition, four sub-activities of IDV development were mapped with established norms for leading the development, including data, model, visual representation and interaction. In sub-chapter 6.4.2, the think-aloud session allowed users to express their explanation of interaction, feedback toward the current IDV such as highlighted findings as well as spotted puzzles.

6.4.1 Initial IDV development

Based on the initial requirements, a 3-tier application architecture (Figure 6-3) was constructed with specification of technical deployment on layer of data, application and interface. Overall, Tableau Toolkit was employed for the IDV development, since it has a set of well-developed and generically connected tools covering data connectors (APIs), databases, automated visualisation application and online accessible dashboard interface. However, the focus of this illustrative case study is to further apply and develop the FINVID for guiding the IDV development. It constitutes a method which can be generally applied to any visualisation tools and platforms. Thus, in this illustrative case study, FINVID was illustrated based on Tableau software, but it does not necessary depend on a specific platform only.

The specific description of 3-tier software architecture can be found in (Figure 6-3). On the layer of data, a Tableau generic SQL database was employed to retrieve data from external sources (e.g. Canadean market research) and internal sources (e.g. user inputted data like BCI score in the sub-chapter 7.7.2). At the initial design, the data retrieval from the data sources are event triggered when data updating notification is received, since the market research data are usually updated on a quarter or annual basis. It can also be further adjusted to time triggered (e.g. every 12 hours or daily) if in the future the IDV is used for monitoring market and sales performance in a daily basis. At the application layer, Tableau (server) was employed for data processing as well as for data visualisation. It includes data warehouse functions supporting ETL operations with the underlying databases and automated visualisation toolkits for generating visual representation and deploying interactive functions. At the interface layer, Tableau dashboard was employed, which can allow the IDV user interface to be

accessible online where diverse users from different locations can easily access the IDV product once they have been authorised with a user account. Other than the 3-tier architecture, the activities of requirement management are implemented during the whole process of IDV development, which outputs the norms to guide the development on each layer. It gives an opportunity to users to continuously specify the information needs and help IDV serve users' understanding, interpretation and sense-making of dataset.

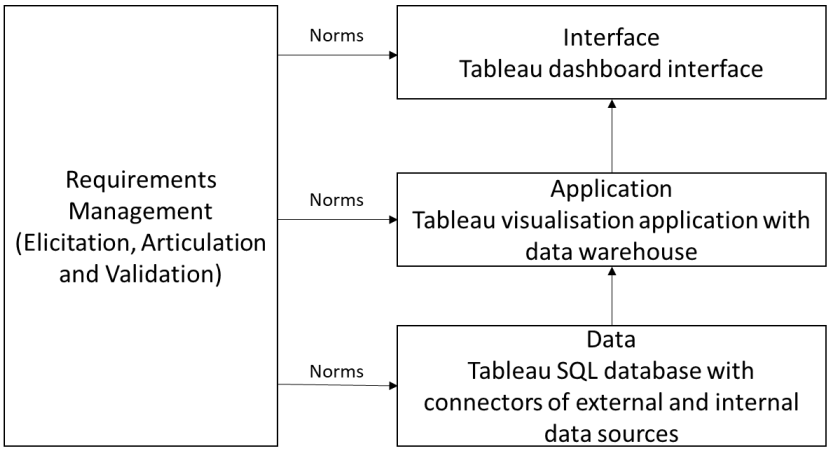


Figure 6-3 3-tier software architecture (IDV development for market intelligence)

With regard to developing the initial version of IDV, the norms articulated in table were further mapped with four sub-activities to guide IDV development. This includes: 1) collecting data with specification of data source, metadata and data properties; 2) establishing model with specification of processing methods and algorithms of preparing data for visualisation; 3) selecting visual representation with specification of chart type, layout, colour and design principles; 4) designing interactions with specification of interaction purposes and corresponding functions. The specific description of initial IDV design is demonstrated in Table 6-7 and artefact is displayed in Figure 6-4.

Table 6-7 Sub-activities of IDV development in the initial loop

Sub-activities	Techniques and methods of developing IDV	Associated norms
Collecting data	Data retrieved via Canadean market research API (2015) and stored in Tableau SQL database. Retrieved data objects: country_name, country_code, total_sales, total_volume, annual_growth_rate(sales).	mrk_size_1-1 mrk_value_1-1 mrk_value_1-4
Establishing model	Modelling techniques. Sum() for directing presenting the selected data based on the conditions: sum(total_voloume) where year=2015. Growth_rate() for calculating the annual growth rate between (t, t-1) Average() for calculating the average of selected variable based on the data of all 80 markets.	mrk_size_1-2 mrk_value_1-2 Mrk_growth_1-2
Selecting visual representation	Referring to (Figure 6-4), bar chart (horizontal) for demonstrating a comparison view. Size indicating the amount of corresponding data object.	Mrk_size_1-3 Mrk_value_1-3 Mrk_growth_1-3

Designing interactions*	Annotation for linking to further explanation including Figure 6-4 showing and ranking. Association for linking the selection of country between bar chart and map e.g. a country can be located on the map once it has been highlighted on the bar chart. Selection for selecting the data of a specific country when inputting the country name or country code.	Mrk_size_1-3 Mrk_value_1-3 Mrk_growth_1-3 Control_1-1

*Description of interactive functions can be referred to the categories of Yi *et al.* (2007) (Table 2-3)

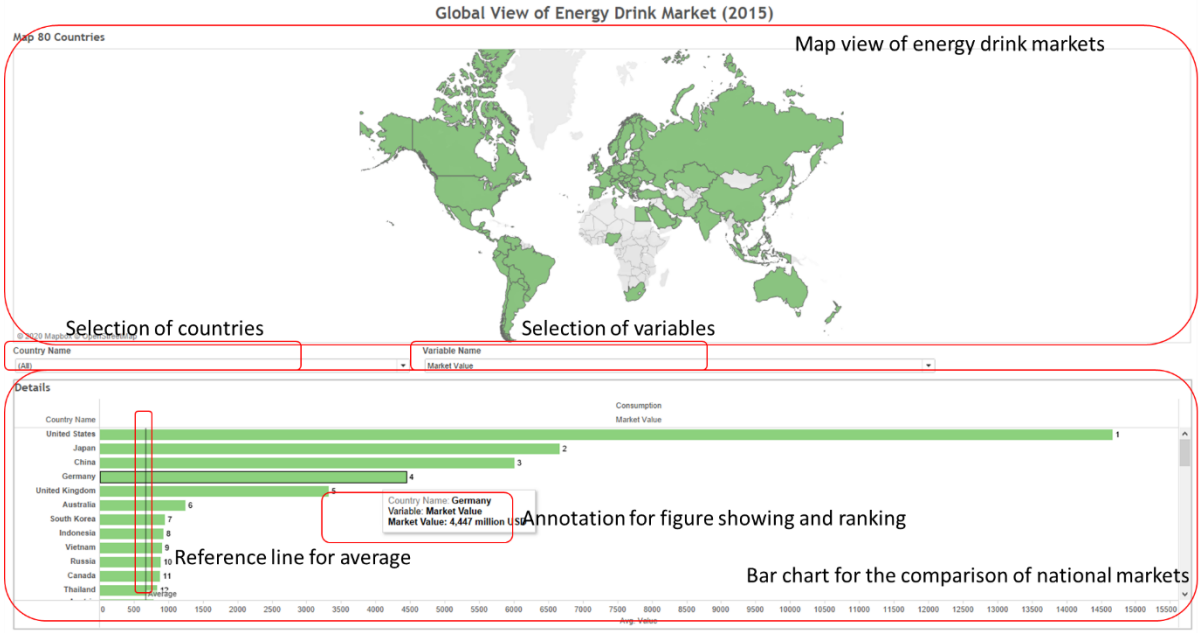


Figure 6-4 Single variable analysis

6.4.2 Think-aloud Session for Initial User Feedback

After the construction of the initial IDV prototype, the users were invited to attend the think-aloud session where they (the users) could leave immediate feedbacks while interacting with IDV interfaces. The analyst was sitting beside the users to capture the feedback information. In addition, a semi-structured interview was also implemented in order to encourage users to talk through the information that they obtained from the interface, including the overview (the general understanding of dataset), highlighted findings (the findings corresponding to the information needs), and spotted puzzles (the unclearly demonstrated information that they would like to discover further) (Table 6-8).

Table 6-8 Key focuses on think-aloud sessions

Key aspects	Sample questions and probs
Overview	What is your general understanding based on the initial data visualisation? Prob: Based on the visualisation, I am aware … (variables and value) Prob: I think (visualisation or interactive function) is very helpful for …
Highlighted findings	What are your key findings based on the initial data visualisation? Prob: It associates with my question …. It reveals that ….

Spotted puzzles	What are the further questions you would like to ask? Prob. It is not clear that …. I therefore would like to further explore …

For the overview of dataset, users expressed that, compared to reading thought the report-style demonstration, visualising the data in a bar chart is much easier to read and to compare. In addition, the selection function is very helpful for users to focus on a few markets in which they are interested, and associated figures of market value and volume can be highlighted correspondingly. Overall, the energy drink market constitutes 1.7% of global soft drink market, but with a strong growth rate on consumption volume 6.1% compared with 1.17% on soft drinks and 1.76 on alcoholic drinks. There are examples of highlighted comments associated to the dataset overview (Table 6-9).

Table 6-9 Examples of overview propositions

Proposition tag	Example of propositions
Overview_1-1	For market value, the average value of a national market is 678 million USD. Out of 80 selected major markets from the database, there are 16 markets with a market value above average which are located in Northern America, Asia and Western Europe.
Overview_1-2	For total volume, the countries with large populations are in the leading positions, such as China, Japan and United States.
Overview_1-3	For annual growth, the average growth rate of market value is 6.1%. Eastern Europe as well as Asian countries demonstrates a strong growth.

Based on the observation of IDV, the users pointed to key findings which matched their information needs. There are some examples of highlighted findings captured from the think-aloud session presented below (Table 6-10).

Table 6-10 Examples of propositions of highlighted findings

Proposition tag	Example of propositions
Highlighted_finding_1-1	For market value, the top five markets with the highest market value are: United States, Japan, China, Germany and United Kingdom. In comparison, home country Thailand is ranked 12th.
Highlighted_finding_1-2	For market value, the market value of Vietnam and Indonesia were underestimated, which constitute a market value of 913 million USD (ranked 9) and 926 million USD (ranked 8) respectively. They are ranked higher than Nigeria (ranked 26) and even Thailand.
Highlighted_finding_1-3	Market volume demonstrates the consistent pattern with market value, which reveals that the highest consumption of energy drinks are in the region of Northern America, Western Europe and Asia.
Highlighted_finding_1-4	For the annual growth of market value, India, Slovakia and EI Salvador show prominent growth on the market value, compared to the average.
Highlighted_finding_1-5	The leading national market such as China with a large population also shows a strong growth of market value (above average).

Meanwhile, the users also pointed to spotted puzzles which can be explained properly based on the observation of visualisation and which require further actions to incorporate extra data and extra input of experts' knowledge. The spotted puzzles can be regarded as fundamental information for generated new requests to further develop IDV product. There are examples of spotted puzzles in Table 6-11.

Table 6-11 Examples of propositions of spotted puzzles

Proposition tag	Example of propositions
Spotted_puzzle_1-1	It seems that population plays a very important role, and the countries with large populations will generate high market value. Therefore, the impact of other factors, such as market competition and consumption, are not revealed in the IDV.
Spotted_puzzle_1-2	The variation of unit price across different markets might play an important role in evaluating market value. For example, Vietnam's ranking of total consumption is higher than its market value, but Japan's ranking of market value is higher than its total consumption.
Spotted_puzzle_1-3	The average growth rate during the past three years might not be representative; therefore, India and Pakistan demonstrate strong growth. Instead, we need to examine the proposition based on the long-run growth by incorporating the past five years' performance as well as the market forecast published by the leading consulting companies.
Spotted_puzzle_1-4	Consumption and value would not be enough to evaluate the market performance and market potential. Other factors such as demographic features and business environment like government stability can also be considered.

During the think-aloud session, the information of highlighted findings and spotted puzzles were documented while the users were interacting with IDV, which can be further inputted to step 3 for interpretation with the aid of the experts' knowledge.

6.5 Step 3: Matching and Updating Propositions to The Prior Knowledge

After interacting with IDV prototype, users and experts were invited to attend a consulting workshop. The consulting meeting has two folds, including step 3 for matching between proposition and prior knowledge and step 4 for identifying conclusions and cognition gaps. The purpose of the first fold of consulting workshop in step 3 is to help users interpret the key propositions that they generated in the step 2 with experts' knowledge and experience. In step 2, users can establish propositions, including their highlighted findings which respond to their requirements, as well as spotted puzzles which relate to their requirements but have not provided a clear answer to their questions. Therefore, template based on Table 6-12 was employed to document the key information from the consulting workshop.

- Propositions (highlighted findings): the key findings that the users captured based on the understanding of IDV visual representations; the recognised information responds to the users' information requirements.
- Business Interpretation (highlighted findings): with the aid of experts' knowledge and experience and users' predefined purposes, the key findings can be further interpreted in a business context to reveal the business indication (i.e. what does it mean in the business world?)
- Associated knowledge (highlighted findings): the business interpretation can associate with the users' prior knowledge for the purposes of identifying the consistence or differences with what the users know from their knowledge and experience.

Table 6-12 Interpretation of highlighted findings

Vis Item ID	Propositions	Business Interpretation	Associated knowledge
Initial_Bar_1-1	Highlighted_finding_1-1	In the global market, market value is generated from the major markets, such as US, Japan and China. Therefore, the leading markets tends to be very attractive since occupying a small portion of market share might generate a high value.	China and the US might make up the major markets due to their strong purchasing power with a strong economy, and a large market space with large population, respectively.
Initial_Bar_1-1 Initial_Map_1-1	Highlighted_finding_1-2	Energy drink market in Asian countries such as Vietnam and Indonesia show a high market value than other markets in Africa, East Europe and South America. There might be a strong ongoing fashion of drinking energy drinks in Asian countries, especially the neighbouring countries to Thailand.	Users believed that Thailand as the hometown of energy drinks should be ranked as one of leading markets. Based on their business experience in Nigeria, it should constitute a larger energy drink market than Asian countries, like Vietnam. However, the observation on IDV gives controversial findings – Vietnam is a higher value market for energy drink than Nigeria and even more than Thailand.
Initial_Map_1-1 Initial_Bar_1-1	Highlighted_finding_1-4	Although the national markets in the East Europe do not show either high value or high consumption based on the ranking, it reveals a strong growth based on the market value data. It might offer opportunities for new entrants to take a ride of market growth to generate income.	Since users have very little experience in relation to East Europe markets, the markets of Czech Republic and Slovakia were not on the main list of focused markets. Based on the observation on IDV, the strong growth of energy drink markets in the East Europe might constitute a great market potential in the near future.

Other than the interpretation of highlighted findings, the spotted puzzles were also brought to the consulting workshop. The participation of experts helps users to explain the puzzles as well as the potential causes behind the puzzles. Therefore, based on the consultation, the business interpretation and associated knowledge were documented for each spotted puzzle (Table 6-13).

- Proposition (spotted puzzles): the unclear meaning that the users perceived from IDV, which cannot fulfil the users' information needs due to insufficient data or inappropriate presentation
- Business Interpretation (spotted puzzles): with aid of experts' knowledge and experience and users predefined purposes, the potential causes and indications behind the puzzles would be discovered (i.e. what does it cause the confusion or unclear information in the business context?)

- Associated knowledge (spotted puzzles): the potential causes can be associated with prior knowledge which can help generate the further requests in step 4

Table 6-13 Interpretation of spotted puzzles

Propositions	Business interpretation	Associated knowledge
Spotted_puzzle_1-1	The markets with a large population constitute a large size of consumer market than others. However, over-emphasising the impact of population might lead the neglect of other factors. Therefore, measures per capital or per unit of consumption might reveal weaken the impact of population, for example, incorporate consumption per capita; unit price.	Population is an important fact, which indicates a big market or a potential big market. The national market with large population can be considered, such as China, since a small portion of market share can potentially bring with it a high amount of income.
Spotted_puzzle_1-2	The unit price of energy drink might be different across national markets, which relates to business environment, such as GDP and disposable income. Intense competition might cause a lower unit price than other markets. Health concerns, for example diabetes, might cause the imposition of a sugar tax on energy drinks, which will increase the unit price. Therefore, the unit price and other causes influencing unit price may be discovered.	Large consumption usually indicates a high market value.
Spotted_puzzle_1-3	Direct average of annual growth with time scale of 3 years might not be able to reveal the long-term growth, since the annual growth might fluctuate in the short-term. Therefore, different growth rates calculation with different time scales can be incorporated into the data modelling to reveal the growth potential from a more comprehensive perspective.	Annual growth on market value might reveal the potential of the/a selected market. If the current market value and size of a market is not ranked high but has an outstanding growth rate, it can be regarded as a potential opportunity to set up first-entry advantage.

6.6 Step 4: Identifying the Conclusions and Cognition Gaps

The second fold of consulting meeting focuses on helping users identify useful conclusions which they might take away to facilitate the following actions, as well as cognition gaps where they can address further requests to lead the IDV development. Based on the abductive reasoning process, IDV development needs to iteratively refine and update for responding to the users' requests. In addition, in

step 4, the norms are employed to structuralise and manage users' requests. Five types of norms are utilised to categorised user's requests in order to map to the sub-activities of IDV development in step 6.

6.6.1 Conclusions Articulation

In the part of conclusion, following the discussion of "highlighted findings", users can also make plausible conclusions with the knowledge and experience input from the experts. The purpose of documenting the plausible conclusions is to record what users can make sense of on each loop of IDV development as well as how the conclusions can be updated with the continuous observation of IDV. Then, based on the conclusions, the relevant suggestions can be generated to guide the following actions. In other words, users can make sense of data by thinking of the following actions based on the information that they obtained from the IDV. The example of articulated conclusions can be found in Table 6-14.

- Conclusions: based on the highlighted findings, a conclusion can be drawn with the association of business interpretation in step 3. Associated with the purpose of selecting markets for internationalisation, the conclusions point to one or a cluster of country for consideration
- Suggestions: based on the conclusions, experts can suggest what action can be taken in the business context in terms of further examining the conclusions or making a decision based on conclusions
- Associated "highlighted findings": linking back to the "highlighted findings" for marking where the conclusion is generated

Table 6-14 Key conclusions and suggestions

Conclusion ID	Conclusions	Suggestions	Associated "highlighted findings"
Conclusion_1-1	The national market with a large population, such as United States, Japan and China, has a big market size and generates a high market value. It might be an opportunity for a new energy drink brand to enter into the market, since a small portion of market share can bring an attractive amount of income.	Company C can consider listing China and United States as candidate markets for internationalisation. At the same time, more observation might be necessary to examine the conclusions, such as the intensity of competition, costs associated to the business environment and the business capacities.	Highlighted_finding_1-1

6.6.2 New Requests Articulation

Other than conclusion which can lead the decision and actions in the business operation, "spotted puzzles" can be further analysed for the purpose of addressing more requests. Based on the abductive reasoning process, users should be allowed to continuously address their requests while interacting with

IDV. Since users might not be able to clearly provide all information needs at the initial stage, it is therefore necessary to let the researcher address their information needs during the process of exploring IDV. Then, IDV development can be set into a loop where the development sub-activities can follow the requests for continuously fulfilling their information needs. Thus, the further analysis of "spotted puzzle" can help user configure more requests based on their incremental understanding and interpretation of datasets (Table 6-15).

- Further request: to solve the puzzle and explore more information, the experts and consultants help users configure the further requests which need to be addressed when adjusting the data visualisation.
- Embedded reasons: other than the general goals of IDV development, the experts and consultants help users address the embedded reasons and motives for addressing the request. The documented reasons and motives will be further inputted into the next loop of IDV development, since the interpretation is pragmatic where users expect to interpret the information aligned with their main intention.
- Associated "spotted puzzles": linking back to the "spotted puzzles" for marking where the puzzle is found.

Table 6-15 Further requests

Request ID	Further request	Embedded reasons	Associated "spotted puzzles"
Request_1-1	Adding market consumption per capita into the comparison.	For weakening the impact of the total population. For evaluating the extent to which energy drink consumption is embedded into the resident's lifestyle.	Spotted_puzzle_1-1
Request_1-2	Allowing the display of multiple variables for constituting an integrated view.	For avoiding over-focusing on a single market variable, and diverse variables need to be incorporated, such as market size, value, saturation and growth.	Spotted_puzzle_1-1
Request_1-3	Adding unit price into the comparison.	For discovering the mystery between consumption and market value. For view the variance of unit price across national markets.	Spotted_puzzle_1-2
Request_1-4	Changing the calculation of the annual growth rate to a compound growth rate.	For justifying the long-run growth of energy drink market, instead of merely focusing on short-term fluctuation.	Spotted_puzzle_1-3
Request_1-5	Adding competition market share composition to each national market.	For measuring the competition intensity and potential market space for new entrants.	Spotted_puzzle_1-1
Request_1-6	Adding other market factors, such as demography and	For establishing a compound and comprehensive view of market attractiveness measure,	Spotted_puzzle_1-1 Spotted_puzzle_1-2 Spotted_puzzle_1-3

	business environment, into the market attractiveness measure.	including both market factors and non-market factors (associated to the risks and costs of entering into a new market).	

6.6.3 Norm Categorisation

After addressing conclusions and new requests, the relevant information can be further articulated and structuralised to a norm format with five specifications: context, condition, agent, deontic operator and action. Compared with the narrative records documented in steps 3 4, the requests in the norm format can clearly indicate the change for analysts and developer teams to further develop IDV. For the purpose of facilitating the following cycles of IDV development, all documented norms can be further categorised into five types and they can then be mapped with different sub-activities in the process of IDV development. Compared with norm specification, although the expression of natural language, as the initial input of users' demands, can convey a wide range of information, it is hard to the developer team to identify the key information from the text. Therefore, when it incorporates norm, the information of users' demands can be categorised and connect to the different sub-categories, such as collecting data (Table 6-18), establishing model (Table 6-19), selecting visual representation (Table 6-20) and designing interaction (Table 6-21). The specific description of each norm categories and their main function can be found as follows.

Perception norms help users perceive the sign (visual representations), indicating the selection of charts, layouts and colour codes. Cognitive norms enable users to incorporate knowledge and experience for interpretation, indicating the selection of data objects and sources, and the establishment of data processing models. Evaluative norms help users discover reasons for which users input the purposes and objectives, guiding the perception of visual representations and design of interactive functions. Behavioural norms govern user behaviour during the interaction and navigations, reveals how users expect from addressing requests to IDV, and associates different IDV items for configuring an integrated view of dataset. Denotative norms direct the selection and organisation of signs for signifying depending on the context, which can help the developer to embed the intended navigation and story line into IDV. Therefore, the final IDV product can enable users to explore and share new knowledge with others by demonstrating the whole story line for discovering new knowledge.

The requests from table can be structuralised into the norm format with a tag of norm category, which can be further inputted to the following step for guiding the IDV development (Table 6-16).

Table 6-16 Further norm specification (initial loop)

Norm tag	Categories	Whenever <context>	if <condition>	then <agent>	is <deontic operator>	to <action>

Mrk_CPC_2-1	Cognitive	Market analysis based on consumption.	The consumption per capita is requested.	Users	Permitted	Extract “consumption per capital” from Canadean with the unit of “litre”.
Mrk_CPC_2-2	Perceptive	Market analysis based on consumption.	The data of consumption per capita is collected.	Users	Permitted	Compare the corresponding data objects among the selected 80 countries in a bar chart.
Mrk_CPC_2-3	Cognitive	Market analysis based on consumption.	One or a cluster of countries selected.	Users	Permitted	Highlight the selected countries. Map the locations on the map view. Compare with reference line of average.
Mrk_CPC_2-4	Evaluative	Market analysis based on consumption.	The map view of consumption per capita is presented.	User	Permitted	(Traffic light indicator) Input a reference level. Mark the country above reference level with green colours. Mark the country under the reference level with red colour.
Mrk_MAI_2-1	Cognitive	Market Attractive Index (MAI) analysis	Data consumption, competitiveness, growth, demography, and market environment.	User	Permitted	Implement an index configuration with the data of five main variable categories.
Mrk_MAI_2-3	Denotative	Market Attractive Index (MAI) analysis	MAI map view is displayed.	User	Permitted	Input the weight of each category of variable based on the assumed importance. The weigh value scales from 0 to 1 (0-least important; 1-most important).

Mrk_Nav_2-1	Behavioural	Understanding the measure of MAI for selecting new markets for internalisation.	After viewing the results of single variables and multiple variable comparison.	User	Permitted	Associate with the selected countries from the single/multiple variable view to the index view. Observe and analyse the position of the selected countries on the MAI/BCI matrix.

6.7 Step 5: Further Constructing Data Visualisation based on Further Requests

After the consulting meeting demonstrated in steps 3 and 4, the new user requests documented in a norm format were inputted into step 5 to further developing IDV. Based on the abductive reasoning process, the development of IDV is not a "one-off" process but is continuously refined based on the updating user requests. Especially with aid of a norm, the requests can be clearly communicated to the developer team for them to understand users' information needs (i.e. the data that they are looking for), intentions for interpretation (i.e. how they prefer the data to be selected and presented for facilitating their interpretation) and sense-making process (i.e. in what sequences and association among different visual representation they can explore their knowledge and configure an integrated view to guide the following actions).

Based on the cognition gaps and new requests, the cognition loop will be triggered (Figure 5-3). Within the loop, the users can continuously address the new requests while interacting with IDV. At the same time, with the iterative engagement of users, experts and developer team, the functions of IDV would be gradually established and refined for fulfilling diverse and updated user demands, which start from understanding the key patterns of datasets, to interpreting the key message revealed via IDV, and to make sense of facts for facilitating the following actions. In the illustrative case study, the development cycle consists of four loops of IDV development (Table 6-17), which are demonstrated in the sub-chapters.

Table 6-17 Four loops of IDV development

Loop	Data Visualisation Production	Main focuses on data object
1	Single variable visualisation	Single variables for measuring market attractiveness: market value, size, growth.

2	Multi-variable visualisation and MAI Index	5 main categories of MAI variables: consumption, growth, competition, demography, business environment. Market attractiveness index (with a comparison view).
3	Matrix analysis	MAI and Business Competence Index (BCI) for market selection.
4	Navigated analysis with a story line	Data Story with 3C model (Context, Content and Conclusion) for presenting and sharing the same vision with the board and shareholders.

6.7.3 Loop 2: Multiple-variable Visualisation with Index Analysis

In loop 2 of IDV development, the norms articulated in loop 1 were inputted as a foundation for further developing IDV. To be specific, based on the norm categories and its corresponding functions, they can be mapped to different sub-activities of IDV development for guiding the actions of collecting extra data, refining/establishing new data processing models, selecting appropriate visual representations, designing interactive functions and setting navigation path for data exploration.

Based on the requests of incorporating market as well as non-market data, other than Canadean market research data, the data objects for measuring business environment and demography were also collected from the open database of World Bank and World Economic Forum (Table 6-18).

Table 6-18 Key data objects for data collection

Variable category	Data object	Data Sources	Associated norms
Consumption	Market value (million USD)	Canadean report (2015)	Mrk_MAI_2-1
	Unit price (USD/litre)	Canadean report (2015)	Mrk_MAI_2-1
	Consumption per capita	Canadean report (2015)	Mrk_CPC_2-1
Market growth	Projected growth on market value (2015-16)	Canadean report (2015)	
	Market size (million litre) – consumption of energy drinks 2009-2014 (*for growth calculation)	Canadean report (2015)	Mrk_CPC_2-1
Competition	Market share top 3 brands in each market	Canadean report (2015)	Mrk_MAI_2-1
	GDP per capita by country (for MSI calculation)	World Bank (2015)	Mrk_MAI_2-1
Market environment	Global Competitiveness Index (GCI)	World Economic Forum (2015)	Mrk_MAI_2-1
	Foreign Direct Investment (FDI) Inflow	World Bank (2015)	Mrk_MAI_2-1
	Diabetes percentage in population	World Bank (2015)	Mrk_MAI_2-1
	Political stability score	World Bank (2015)	Mrk_MAI_2-1
	Regulation-friendliness score for foreign companies	World Bank (2015)	Mrk_MAI_2-1

	Internet users per 100 residents	World Bank (2015)	Mrk_MAI_2-1
Demography	Urban residents	World Bank (2015)	Mrk_MAI_2-1
	Urban Residents (age 15-64)	World Bank (2015)	Mrk_MAI_2-1
	Population (age 0-14)	World Bank (2015)	Mrk_MAI_2-1

Based on the norms, the collected data can be further inputted for being modelled to MAI variables, which consists of five main categories and 18 variables (Table 6-19). Afterwards, all 18 variables can be further utilised for calculating the Market Attractiveness Index (MAI). With the incorporation of diverse measures of market and non-market factors, MAI can deliver a comprehensive view of market potentials that Company C might access (high score means high market potential).

Table 6-19 Key variables and data modelling techniques

Variable category	Key variables	Data Modelling
Consumption	Market value (million USD)	Direct quote
	Unit price (USD/litre)	Direct quote
	Consumption per capita	Direct quote
Market growth	Projected growth on market value (2015-16) (million litre)	Direct quote
	Growth of market size (million litre) (2009-2014)	Direct quote
	Compound Annual Growth Rate (CAGR) on Market Size (percentage) (2009-2014)	CAGR equation
Competition	Market saturation index (MSI)	MSI
	Market Share of Top 1 Brand (Parentage)	Direct quote
	Competition Intensity	CI
Market environment	Global Competitiveness Index (GCI)	Direct quote
	Foreign Direct Investment (FDI) Inflow	Direct quote
	Diabetes percentage in population	Direct quote
	Political stability score	Direct quote
	Regulation-friendliness score for foreign companies	Direct quote
	Internet users per 100 residents	Direct quote
Demography	Urban residents	Direct quote
	Urban Residents (age 15-64)	Direct quote
	Population (age 0-14)	Direct quote
Compound Index	Market Attractiveness Index	MAI

Compound Annual Growth Rate (CAGR) measures the growth rate of market size (09-14). Since it takes five years of historical growth in account, users believe that it reveals a more creditable momentum of market size growth (Equation 6-1).

Equation 6-1 CAGR (market size 2009-2014)

$$CAGR = \left(\frac{Market\ size\ (2014)^{\frac{1}{5}}}{Mark\ size\ (2009)} - 1 \right) \times 100\%$$

Market saturation index (MSI) measures the market potential for improving the consumption of energy drinks (Equation 6-2). The users decide to use the United States as an initial benchmark for setting the maximum amount of consumption per capita. Then, via this variable, users can compare each market with US and measure the potential space of growing the consumption per capita in the selected market. In addition, users also believe that with the more space for GDP growth and its corresponding affordability, the more potential growth in the consumption of energy drinks. Therefore, for MSI, higher score means lower potential.

Equation 6-2 MSI calculation

$$MSI_x = \frac{Consumption\ per\ capita_{\ x}}{Consumption\ per\ capita_{US}} * \frac{GDP\ per\ capita_x}{GDP\ per\ capita_{US}}$$

Competition intensity (CI) is measured by the sum of market share of the Top 3 brands (Equation 6-3). If 70% of market share were occupied by the top 3 brands, there might be little space for new entrants to develop their business. Therefore, high value means intensive competition.

Equation 6-3 Competition intensity

$$Competition\ intentsity = Market\ share_{top\ 1\ brand} + Market\ share_{top\ 2\ brand} + Market\ share_{top\ 3\ brand}$$

For the purpose of adjusting values measured on different scales to a notionally common scale, all variables will be normalised to between 1 and 100 by the following indexing approach (Equation 6-4).

Equation 6-4 Indexing equation (1-100)

$$V_n(indexed) = 1 + \frac{V_n - V_{min}}{V_{max} - V_{min}} * (100 - 1)$$

$$V_{nNew}(revese\ indexed) = 101 - \left[1 + \frac{V_n - V_{min}}{V_{max} - V_{min}} * (100 - 1) \right]$$

Echoing the request of integrating the market and non-making factors, Market Attractiveness Index as a comprehensive index with a sum of diverse variables was constructed. It startes with the MAI value. It consists of all 13 variables (n scaling from 1 to 13 indicating 13 variables). For each variable, users are allowed to set a weight scaling from 1 to 10 (0 means unimportant, and 1 means most important). For facilitating the comparison of MAI across markets, MAI value was normalised to the scale from 1 to 100 (Equation 6-5).

Equation 6-5 MAI Score calculation (1-100)

$$MAI\ value = \sum_{1}^{n} Variable_n \times Weight_n$$

$$Weight_n = [0,10]$$

$$MAI\ score_n = 1 + \frac{MAI_n - MAI_{min}}{MAI_{max} - MAI_{min}} * (100 - 1)$$

After the establishment of data models, the well-developed variables can be further connected to the visual representations. The selection and design of visualisation took account of variable content, and users purposes that are reflected from norms, and designing principles such as colour, size and position to fulfil users' demands (Table 6-20).

Table 6-20 Selection of visual representations

Visual representation	Main functions	Key features	Associated norms
Bar_2-1	Bar chart associates with the demonstration of comparison among different national markets as well as among different selected variables based on the value.	Colour refers to variable categories e.g. consumption (blue) and competition (green). Size refers to the value of each variable. The horizontal scale market: being adjusted based on the unit associated to variable content.	Mrk_CPC_2-2
Map_2-1	Map refers to the demonstration of geographic location of selected national markets for showing the distance and proximity among them	Position refers to the geographical locations on a world map.	Mrk_CPC_2-3
Map_2-2	Map used to demonstrate the market distribution of energy drink brands, including market share in different national markets and market value. Map also used to compare the market share of an energy drink brand across different national markets.	Colour (map) for differentiating different energy drink brands e.g. Red Bull (red) and Monster (green). Size (dot) for demonstrate the scale of market value. Colour (colour) for differentiating high value markets and low value markets based on a user defined benchmark.	Mrk_CPC_2-4
Map_2-3	Map applied to show MAI index and market value in different national markets to facilitate the comparison	Colour (map) for differentiating the markets with high MAI value (red) and with low MAI value (blue).	Mrk_CPC_2-4

	based on geographic locations.	Size (dot) for measuring market value in different national market.	
Table_2-1	Table applied to demonstrate the MAI ranking among different national markets.	Sequence for showing the ranking of national markets based on MAI score.	Mrk_MAI_2-1

Other than the deployment of visual representations, the norms can also inform interaction design for responding to the user's exploratory requests. It enables them to examine the results in different conditions and parameters (Table 6-21).

Table 6-21 Interactive function design

Interactive function	Explanation in the context of data visualisation	What-if scenarios	Associated norms
Selection_2-1	Selection for providing users with the ability to select one or a group of countries for checking the geographic location and the value of selected MAI variables.	If one or a group of countries is selected, where is the geographic location? What is their value of MAI variables? Which one is the leading market with the highest score?	Mrk_Nav_2-1
Selection_2-2	Selection for providing users with the ability to select one or a group of MAI variables.	If one or a group of MAI variables is selected, what is the difference between the value of MAI variables among selected markets?	Mrk_MAI_2-3
Selection_2-3	Selection for providing users with the ability to focus on one energy drink brand for checking its market share in different markets.	If a brand is chosen, what is the geographic distribution of its market share?	Mrk_MAI_2-3
Fileting_2-1	Fileting market below the benchmark of market value.	Since we are considering the market with an annual market value below 500 million USD, how many countries can still stay above the benchmark and where are they?	Mrk_MAI_2-3
Annotation_2-1	Annotating detailed description of market value, leading brand and its market share to each geographic sign of national market.	If a country is focused on the map, what is the corresponding market value and market share of the leading brand?	Mrk_Nav_2-1
Selection_2-4	Selection for enabling users to input weight to each category of MAI variables based on the	If I weigh higher or lower to a MAI variable, what is the impact toward MAI index to	Mrk_Nav_2-1

	perceived importance, which can further impact the calculation of MAI.	each national market? Might the top ranked market be changed?	

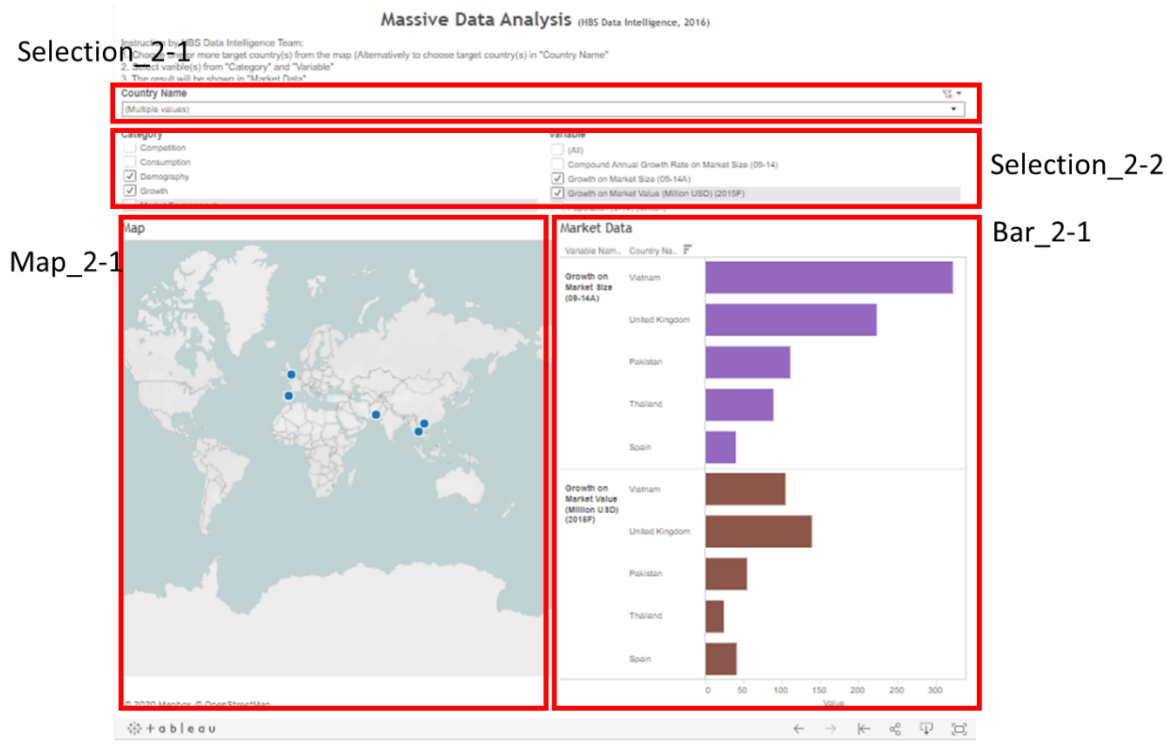


Figure 6-5 Multiple variable analysis

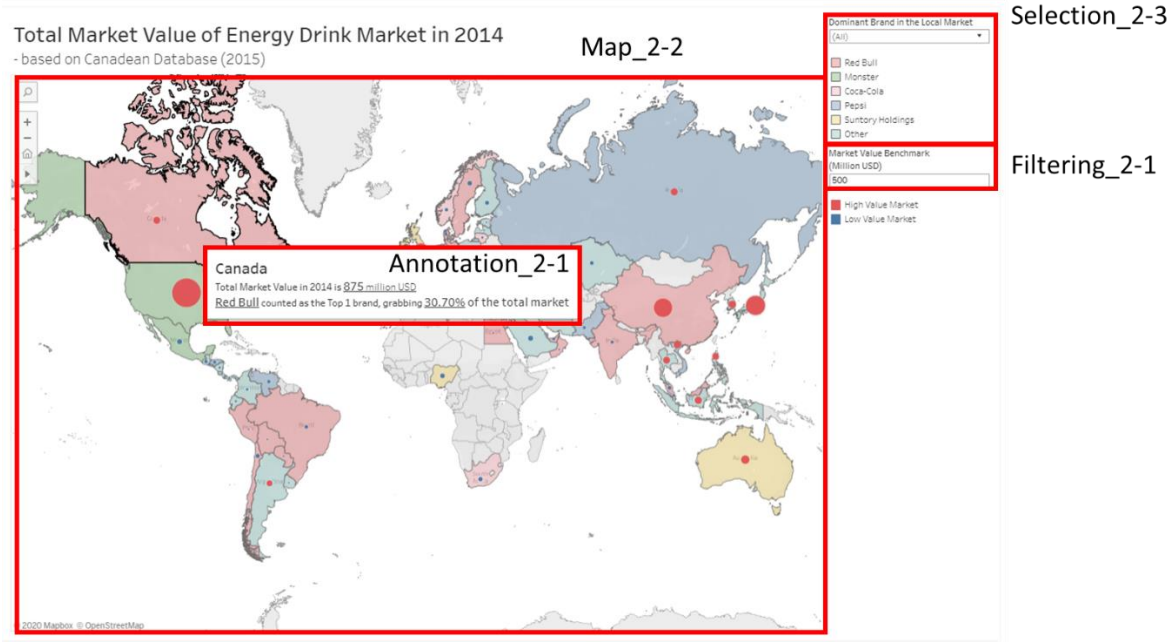


Figure 6-6 Competitor analysis

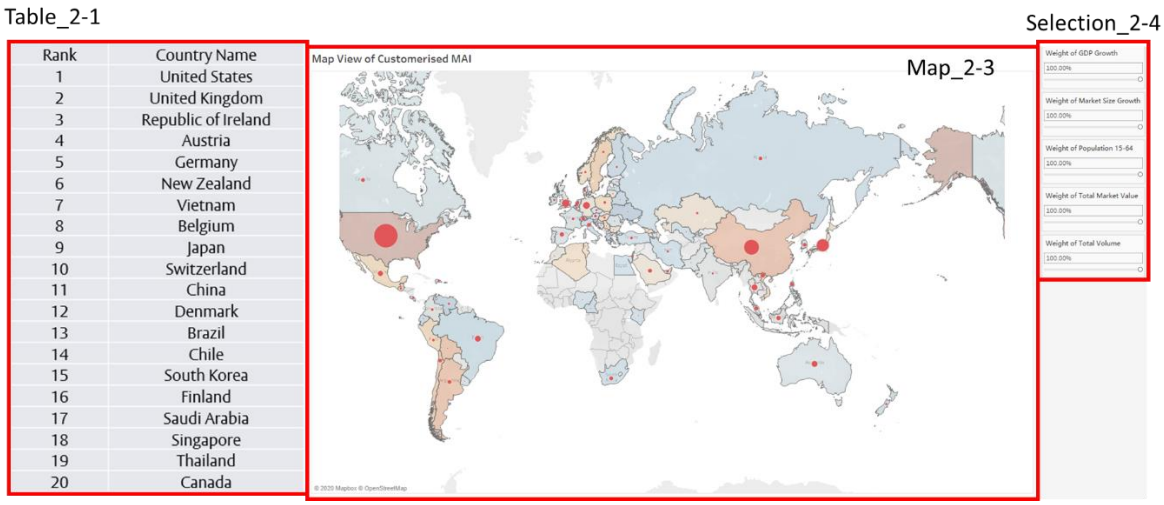


Figure 6-7 MAI map view

Once the visual representations and interactive functions had been fully prepared, the navigation path among different visual representation and interactive function were constructed (Table 6-22). Based on the norms with experts' suggestions and interpretation, the users can explore the IDV via one of the suggested navigation paths. It can enable data objects to be presented via different stages and different layers, which can help with easing the perception and cognition workload.

Table 6-22 Navigation construction

Navigation sequence	Visual representation and key purposes
1 – Key MAI variables	Bar_2-1: Select key MAI variables and make a comparison among different markets
2 – Select candidate markets	Map_2-1: Observe the geographic locations of selected markets
3 – investigate competition situation	Map_2-2: Investigate the market competition status of selected market (leading brands and market value)
4 – Input weights	Selection_2-4: Input the weight to each category of MAI variable based on the perceived importance
5 – Rank markets	Table_2-1: Check the position of selected market(s) on the MAI ranking
6 – Finding a market cluster	Map_2-3: Observe the location of selected markets as well as the neighbour markets which might constitute a market cluster

Following the process of development loop (steps 3, 4 and 5), a think-aloud workshop and consulting meeting were scheduled to involve users, experts and developer teams. For loop 2, users expressed the view that it constitutes a more appropriate method for measuring market attractiveness. With users' and experts' experience, a list of national markets with a high MAI score has been identified to be the target market for internationalisation. However, there were new requests of exploring and measuring the business capacities of Company C. Since when entering a new market, not only should this market contain a great potential of growing new business, but also should the new entrants possess sufficient

resources and capacities of exploring the selected market. Thus, the new requests would be further addressed in loop 3 where IDV can be further developed for fulfilling the users' updated demands.

6.7.4 Loop 3: Matrix Analysis with MAI and BCI

Loop 3 aims to develop the IDV with capacity of measuring and visualising the business capacities of Company C. A new index named as Business Capacity Index (BCI) as established to explain if Company C is capable of reaching each market. In addition, user also requested to demonstrate the growth potential along with MAI and BCI, based on the market growth forecast published by Euromonitor, one of leading market consulting agent. For addressing the requests of selecting attractive as well as feasible market for internationalisation, a matrix analysis with the involvement of MAI, BCI and Potential Growth. Table 6-23 demonstrates seven sub-activities of IDV development in the loop 3.

Table 6-23 Seven sub-activities of IDV development (loop 3)

Sub-activities	Actions in IDV development
Collecting data	Data of Business capacity measures collected via a survey with key stakeholders. Sales forecast (2015-2020) collected from Euromonitor database. MAI scores inputted from loop 1.
Establish model	BCI index
Selecting visual representation	Bubble chart with matrix dimensions for comparing all national markets via position, dimension and size. Position refers to the measure of MAI and BCI score. Size refers to the value of sales potential. Dimension refers to quadrant.
Designing interaction	Annotation for presenting the detailed information of MAI and BCI score, and the exact value of sales potential. Elaboration for connecting to the map view to show the geographic location and specific values of MAI variables when a market is selected. Selection to enable users to set a weight for each BCI variable for examining the change of BCI score under different conditions.
Setting navigation	Bubble chart for analysing the position with MAI and BCI score (right-top quadrant). Bubble chart for finding the market with the greatest sales potential (size). Elaboration for connecting the map view (location) and bar chart (MAI variables). Map view for competition status analysis and for evaluating if there is sufficient market space for growing a new business.

A business capacity survey with 18 variables was implemented with the key stakeholders, and agreed results were outputted to the IDV development process, specifically for data collection and model establishment. The survey and indexing approach of BCI are demonstrated in Table 6-24.

Table 6-24 18 BCI variables in the BCI survey

Category	No	Name	Explanation
Capability&Resources	1	Skill/Experience	Expertise skill and behaviours of the company's people in relation to the host country (i.e. language skills, cultural familiarity and number of experienced managers).
	2	Business Network	Business network capabilities in host country (e.g. finding a partner company such as retailers, manufacturers, investors).

	3	Marketing Capability	Marketing capabilities and effectiveness in host country (country specific know-how, partners etc).
	4	Distribution	Effective distribution capabilities in host country.
	5	Market Development	New market development capabilities in host country.
	6	Finance	Ability to fund market entry and business operations in host country.
	7	IT	IT capability in host country.
	8	Product	Production capabilities in host country.
	9	Long-term	Long term commitment ability to host country.
Competitive Strengths	10	Price	Price acceptability in host country.
	11	Profit Margin	Contribution margins in host country: a product's price minus all associated variable costs, resulting in the incremental profit earned for each unit sold.
	12	Market Share	Obtainable market share in host country.
	13	Fit-to-Demands	Products fit to the market demands in host country.
	14	Brand Image	Product/company image perceptions in host country.
	15	Culture/Social Similarity	Cultural/Socio Economic similarities between company and host country.
	16	Production facilities	Proximity of production facilities to host country.
	17	Football Culture	Product/company image perceptions in host country based on marketing association with football popularity and specifically the Chelsea FC sponsorship.
	18	Legislation	The capability to fulfil the requirements of law and regulation in the host country.

Following the similar procedure with MAI indexing approach, the Business Capacity Index, a comprehensive index with a sum of diverse variables, was constructed (Equation 6-6). It consists of all 18 variables (n scaling from 1 to 18 indicating 18 variables). For each variable, users are allowed to set a weight scaling from 1 to 10 (0 means unimportant, and 1 means most important). To facilitate the comparison of BCI across markets, MAI value was normalised to the scale from 1 to 100.

Equation 6-6 BCI calculation

$$BCI = \sum_{1}^{n} Variable_n \times Weight_n$$

$$Weight_n = [0,1]$$

$$BCIscore_n = 1 + \frac{MAI_n - MAI_{min}}{MAI_{max} - MAI_{min}} * (100 - 1)$$

Based on the collected data and established data model, MAI, BCI and sales potential can be mapped in a bubble chart (Figure 6-8). Inspired by the political direction matrix (Gaston-Breton and Martín Martín, 2011), the matrix can be divided to four quadrants (regions 1, 2, 3, 4), indicating high attractive

and feasible quadrant, medium attractive region, medium feasible, low attractive and feasible region, respectively. The size of bubble reflects the sales potential for the period between 2015 and 2020.

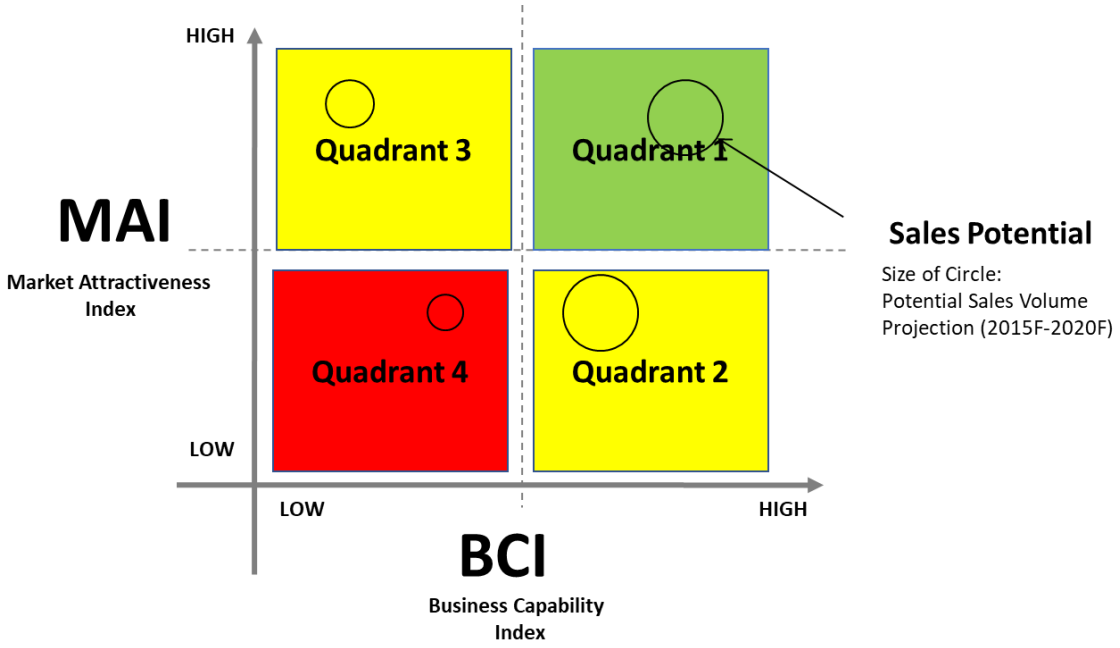


Figure 6-8 Market Selection Matrix (MSM) (conceptual model)

During the consulting meeting, the participation of experts and consultants helped users to analyse four quadrants on the Market Selection Matrix (Table 6-25 and Figure 6-9).

Table 6-25 4 Four Quadrants of MSM

Quadrant	Explanation in the context of Company C.
Quadrant 1	It includes the national markets with high attractiveness for foreign entrants and high feasibility for Company C to enter the market with the accessible resources and capacity. Company C might prioritise them for internationalisation. Examples: China, UK, US and Japan.
Quadrant 2	It includes the national markets with medium or low market attractiveness but high feasibility for Company C to enter. Company C might enter the markets in a light (low investment) approach to further examine its market growth or grow together with the market trends. Example: Australia.
Quadrant 3	It includes the national markets with high market attractiveness, but Company C might not possess enough capacity to enter into the market. Company C needs to further build their capacity via collaborating with the local partners Examples: Kazakhstan and India.
Quadrant 4	It includes the national markets with low market attractiveness, and Company C cannot access the market due to insufficient resources. Company C might not consider the markets at this stage but will keep monitoring the potential dynamics occurring in the markets, such as a sudden growth boosted by the new policy. Example: Tunisia.

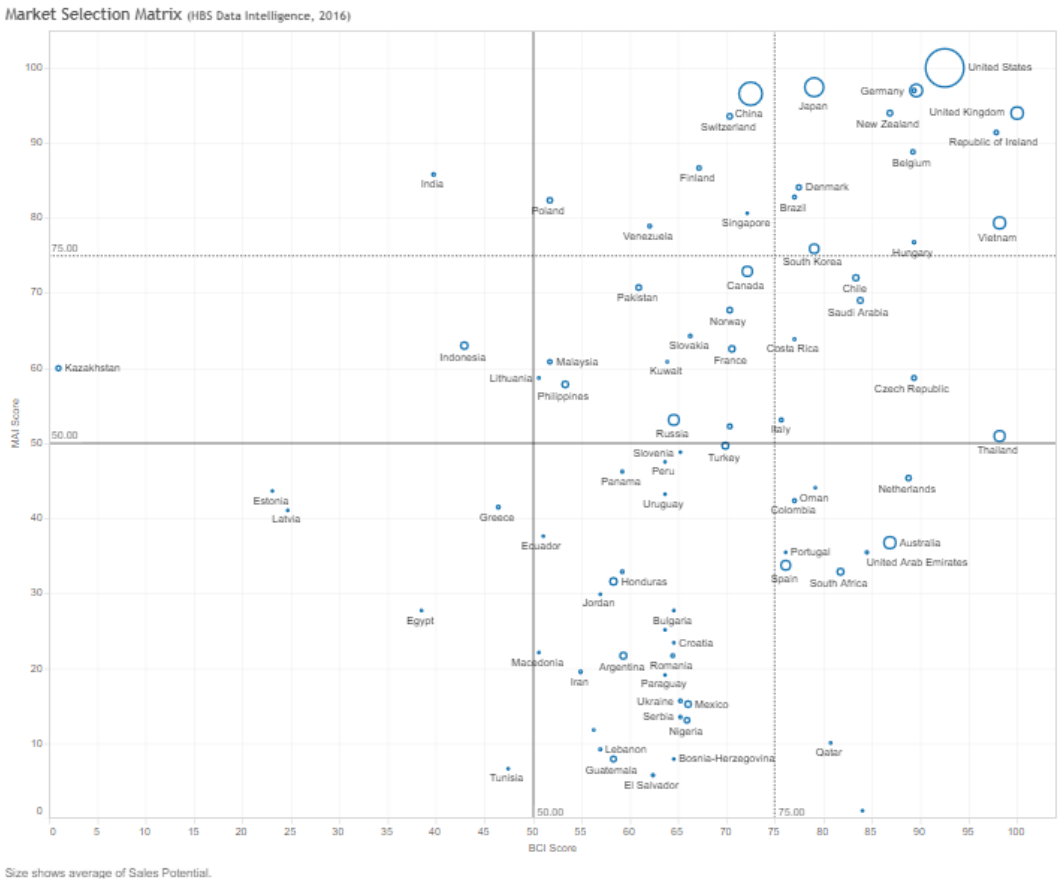


Figure 6-9 MSM in IDV

During loop 3, the users generated a list of target markets with reasonable attractiveness and feasibility for new entrants. However, other than the above conclusions, the users also addressed further requests that they would like to discover the possibility of establishing a market group where instead of focusing on a single big market, Company C can enter into the multiple medium or small market since it might be able to explore new market opportunities and avoid direct competition with the mature brands on the current market. In addition, since the executive team of Company C was required to present a global market research to the board and key shareholders, this requires constructing a story line to demonstrate the results as well as the reasoning process for identifying the key markets for internationalisation strategy. The above requests further triggered loop 4 of IDV development.

7.7.3 Loop 4: Navigated Analysis with a Story Line

Based on the suggestions from the experts, the new requests can be addressed via a cluster market analysis. Company C can select a market as Hub for developing its brand and product, and then take advantages of the business and culture influence of Hub market, the branding campaign and product promotion can further impact on neighbouring countries (known as Spoke) (Figure 6-10). Therefore, the request can be responded to with the sub-activities of IDV development (Table 6-26).

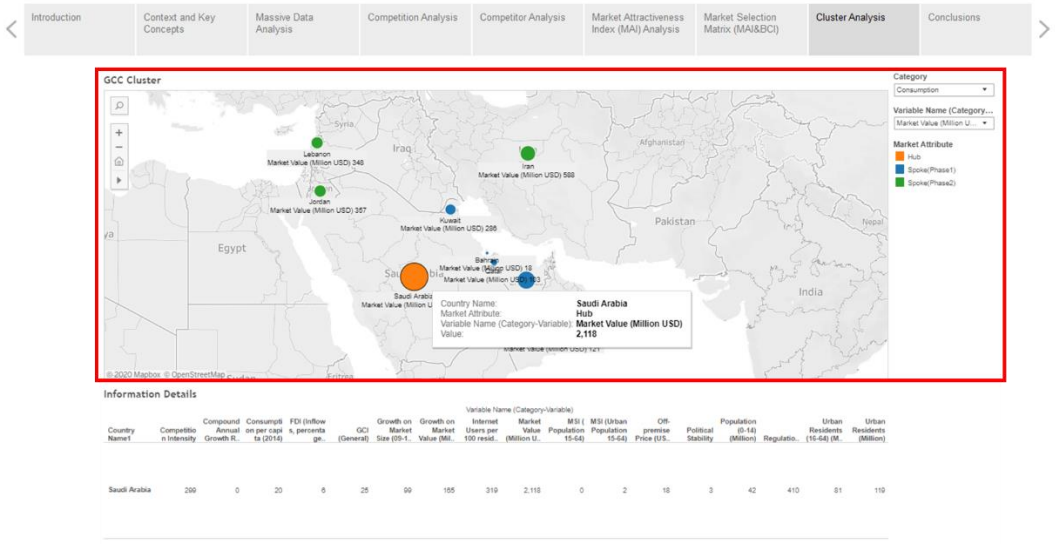


Figure 6-10 Cluster analysis (Hub and Spoke)

Table 6-26 Seven sub-activities of IDV (loop 4)

Sub-activities	Actions in IDV development.
Collecting data	Data query by the name and code of selected markets.
Establish model	13 MAI variables.
Selecting visual representation	Map for showing the positions and proximity of different national markets. Positions refer to the geographical positions of markets. Colours refer to the categories of market (hub or spoke and phrases of entry). Bubble chart for showing the value of selected variable.
Designing interaction	Annotation for presenting the detailed information of country name, market category and value of selected variables. Elaboration for connecting to the table view for displaying the value of MAI variables when a market is selected from the map. Selection for enabling users to set a focus on one or more MAI variables. Colouring for users to assign different colours to the markets on the map for remarking its market category.
Setting navigation	1. Map for selecting one or a cluster of market based on geographical positions. 2. Bubble chart for finding the market with the selected market(s), 3. Elaboration for connecting to the map view (location) and bar chart (MAI variables). 4. Map view for competition status analysis and evaluate if there is sufficient market space for growing a new business. 5. Map view for categorising each market as hub or spoke via marking with different colours.

Other than the view of cluster analysis, a story line was constructed to facilitate the executive teams to communicate the analysis results and to provoke further discussion with the board and shareholders. The story line consists of nine pages (Table 6-27 and Figure 6-11). It follows the 3C structure, including Context (introduction, context description and key concept), Content (massive data analysis,

competition analysis, competitor tracking analysis, MAI analysis, market selection matrix analysis, cluster analysis) and conclusions. The story line can provide an integrated view to track the sense-making process of market selection, while the interactive functions remain on each page for readers to further address the requests to acquire further information and examine different hypothesis on different conditions.

Table 6-27 Story line of IDV

Story line component	Key content and main purposes
1 Introduction	Basic information of IDV, including title, outline of contents, development team, key participants and key contacts for further requests. Purpose: to brief the overall structure and functions of IDV and key contact information for further collaboration. Further requests: contextual information for exploring the IDV.
2 Context description	IDV development background, motivations, purposes, key questions to address and navigation path. Purpose: to brief the contextual information with readers and encourage them to follow the navigation path with consistent purposes. Further requests: viewing a few key variables for establishing an initial view.
3 Key variable analysis	Value of different MAI variables to facilitate users to compare the market performance and status among different markets. Purpose: to establish an initial understanding of market attractiveness via the observation and comparison of single variables (e.g. market value) across markets. Further requests: measuring market attractiveness through an integrated index; viewing further details of market competition status in each market.
4 Competition analysis	Measures of competition intensity in each national market for identifying the leading brands as well as their market shares. Purpose: to evaluate the competition intensity of each market for identifying market space for new entrants. Further requests: Focusing on a specific competitor for viewing its market distribution.
5 Competitor analysis	Geographical distribution of a selected brand, including their market position, market share, consumption volume and market value. Purpose: to identify the blue ocean market where the leading brands do not dominate. Further requests: Measuring the potential opportunities of growing a new business in each market with a consideration of its market and non-market factors
6 MAI analysis	Ranking of national markets based on MAI score for identifying the most attractive markets based on different combination and weights of MAI variables. Purpose: to rank all markets based on its attractiveness and to identify a list of target markets. Further requests: establishing a holistic view with a consideration of MAI (attractiveness) and BCI (capacity) for selecting the most attractive and feasible markets.
7 Market selection matrixes	Matrix analysis of national markets based on MAI and BCI scores (2 dimensions) and sales potential (size). Purpose: to categories market by quadrant and match with different strategies. Further requests: exploring the mutual impacts among different markets.
8 Cluster analysis	Exploration of potential market cluster where the multiple markets can share the same branding campaign or sales channel. Purpose: to explore the potential of formulating market clustering strategy, like Hub and Spoke for entering into a group of markets simultaneously.
9 Conclusions	Documented conclusions based on the highlighted findings. Discussion provoked based on conclusions or new questions. New conclusions updated based on readers' feedback. Purpose: to document all useful findings, conclusion and suggestions for making sense of dataset.

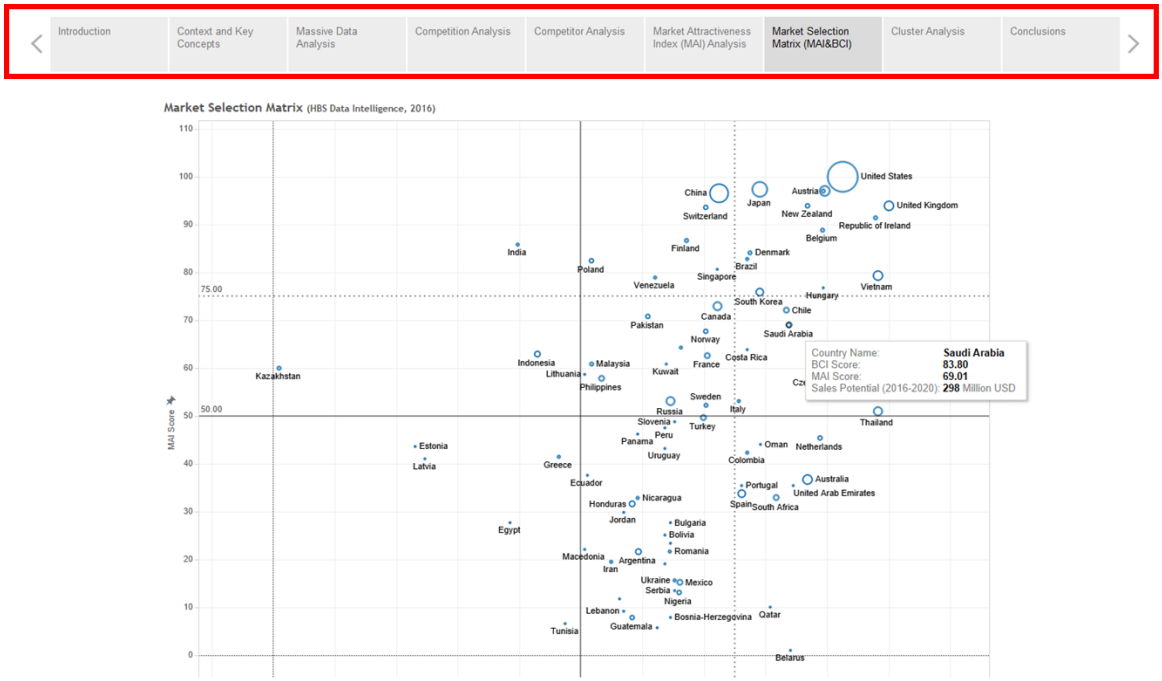


Figure 6-11 Story line in IDV interface

6.8 Step Six: Refining and Generating New Knowledge for Guiding The Following Actions

After four loops of IDV development, the users expressed the view that they have obtained sufficient information from IDV for the market selection at the current stage of internationalisation strategy formation. Therefore, the final consulting meeting was scheduled for wrap up all useful conclusions and generating new hypotheses for being examined in different work scenarios. With the input of experts' knowledge and experience, the conclusions were further developed to actional suggestions, which can further lead to decisions or actions in the business scenarios. At the same time, for some conclusion and unsolved questions, the users might seek different approaches in a different context or with different data input to further examine the validity of conclusions and feasibility of suggested actions. Therefore, the discussion in step 6 has two folds, including conclusion documentation and new hypotheses documentation. The final results were added to the conclusion page of IDV as the analysis outcome.

- Conclusion: the content of conclusion configured based on the IDV product
- Available suggestions: With the help of experts' knowledge and experience, the suggestions that user can take away for implementation in their business context

The examples of conclusions can be demonstrated in Table 6-28.

Table 6-28 Articulated conclusions and suggestions

Tag	Conclusions	Actionable suggestions
Conclusion_1	Based on the overall MAI analysis, China and US are mature energy drink markets with steady growth, high consumption and a friendly attitude toward foreign companies. Although they appear as a fierce market competition among leading brands, a small proportion of market share can potentially generate big income. Therefore, China and the US can be considered at the initial stage of internationalisation.	Based on BCI variables related to business network and culture similarity, China might be prioritised more than the US. Export or licensing approach might be more preferable than FDI, due to the fierce competition on the current market. Therefore, contracting with an existing distributor would be easier and quicker to enter into the market and generate income.
Conclusion_2	Based on the cluster analysis, the GCC market cluster can be explored due to the geographical proximity and rich business connection. The Middle East can constitute a big energy drink market since the ban of alcoholic drinks and widespread fashion and sport culture can drive the young generations to consume more energy and sport drinks. Saudi Arabia can be set as a hub based on the BCI score, and then the production promotion and branding campaign can spread to the spoke market nearby.	For the GCC market, the approach of joint venture or strategic alliance might be helpful. Culture and business systems in Middle Eastern countries are very different from European and Asian countries. In particular, taking account of complexity and unfamiliarity of religious beliefs and social customs, working with local companies would help with enter into the market in a smooth pattern.
Conclusion_3	Based on the MAI analysis on a map view, the UK is the leading market of energy drink in the Western Europe. In particular, its football fashion and culture has a widespread impact on other markets globally. If Company C has the opportunity to take football as a carrier for branding and product promotion, it can bring the brand to a wide global market.	Based on the BCI score, Company C has a strong interest as well as rich resources to use the UK Premium League as a branding channel. Therefore, FDI might be a useful approach to set a business in the UK and collaborate with a Premium League football club via sponsorship. The branding campaign can spread to the European and Asian country for strategic purposes.
Conclusion_4	Brazil can be regarded as a potential market with a growing market size and accessible business capacities. Based on market saturation analysis, it has a great space for consumption growth. Brazil market appears spaces for foreign entrants, like Red Bull (45%) and Coca-Cola (10%).	Referring to the BCI score, Company C is able to access the distributor, finance, and other channel partners. Therefore, entering in Brazil via an approach of joint venture and position itself as a follower of Red Bull.

Examples of new hypotheses/questions are demonstrated in Table 6-29.

- New hypotheses: based on the conclusions, new hypotheses that users would like to further examine in the following actions to justify the conclusions from different perspectives.
- Further examinations: other than the current IDV product, experts might suggest other approaches to gathering data to examine the hypotheses (Table 6-29).

Table 6-29 Articulated hypotheses and questions

Hypothesis Tag	New hypotheses/questions	Further examinations/exploration
Hypothesis_1	For the leading markets, such as the US and China, the geographic coverage is very wide. Therefore, within a national market, the MAI score might be different from place to place.	Therefore, it is necessary to examine further if the consumption and value of energy drink is concentrated in a certain region, which would be the main focus of Company C's strategy.
Hypothesis_2	Health issues, such as obesity and diabetes, constitute another prominent consideration when consuming energy drinks (which contain high volume of sugar).	Further investigation may require evaluating the health-related barriers of developing energy drink business in different market (e.g. 1% of sugar tax in the UK).
Hypothesis_3	Life style can be another important consideration when developing energy drink business in a new market. For example, what is the most common scenario of off-premise consumption?	Off-premise and on-premise consumption data can be further incorporated into IDV. At the same time, in-depth market research needs to be implemented in the selected countries. In Thailand, the majority of consumption of energy drink takes place off-premise, since taxi and track drivers are the major consumers and they prefer to buy a batch of energy drinks (off-premise sales) products to sustain their energy for long-hours of hard work.

6.9 Summary

This chapter illustrates FINVID in a case scenario of IDV development for market intelligence, where six steps of abductive reasoning process and seven sub-activities of IDV development have been used to facilitate the communication and interoperation among users, experts, analysts and developer team. The illustration of FINVID also corresponds to three propositions of IDV development. Firstly, IDV development is a norm-centric process where a norm helps communicate users' prior knowledge and requests, which further helps with the incorporation of users' information needs, interpretation purposes and contextual pressure. The norms help capture and specify the users' requirements on the semantic, pragmatic and social layers of semiotic ladders for facilitating the communication among different individuals. Secondly, IDV development can be implemented in an abductive reasoning process. The four development loops allow users to continuously address the requests for more information in order to justify their hypothesis, which can be documented and analysis in the format of the norm and eventually lead the design of interactive functions. Finally, IDV development enables visualisation to serve as knowledge exploration. In the illustrative case study, the experts, analysts and consultants participated in the IDV development process, in particular helping with eliciting requests and articulating conclusions and suggestions during the development loops. IDV not only makes a visualisation artefact, but also develops a tool as well as procedure for users to exploring their knowledge via making sense of dataset.

7 Validation of FINVID

This chapter focuses on the validation of FINVID from the perspectives of validity, utility, generalizability and innovativeness. Since the refined version of FINVID has not been fully utilised in a wide range of scenarios to witness and measure its capacities and impacts, a series of compound expert interview are adapted in this research for validation purposes. According to Gregor, Müller and Seidel (2013), the expert review is a method of collecting independent opinions from individuals with relevant expertise and experience towards the research objects. Their expertise can consist of academic and systematic understandings, practical experience (incl. insights of industrial practices and issues), and user journey and experience. Based on the paradigm of design science (Mingers and Willcocks, 2017), the expert review can be used as one of important approaches to evaluate the potential impacts generated by the artefact, taking an important reference from experts' prior experience. Inspired by Fischer, Christian and Gregor (2012), the expert interviews cover the all four key aspects of validation, including validity, utility, generalisability and the innovativeness of FINVID on its impact on users' understanding, interpretation, sense-making and communication of datasets.

Overall, seven experts were involved in the review by individual or by group means. The selection of experts is based on their academic focus, practical experience and the degree of involvement during the user journey, which enables them to provide an independent but relevant assessment towards FINVID's design, capacities and impacts. The interview design follows the principles of semi-structured interview. In addition, an interview guideline was provided prior to the interview as a tool to elicit the experts' responses on the validity, utility, generalisability and innovativeness. Other relevant comments were also allowed through open questions and open comments for maximising the opportunities to collect opinions from the experts.

7.6 The Validation Process

Following the principle of design science (Hevner *et al.*, 2004), the expert review interviews can be designed to evaluate the artefacts as well as the process of developing them. The expert interviews in this research allow the expert to understand the framework and its components, to interact with the artefact in a simulated context, and to give feedbacks based on their experience. Therefore, the overall process includes a brief presentation delivered by the researcher covering the introduction of FINVID, process and components on each development stage, a demonstration of artefacts based on the case study context of Global Market Selection, and a feedback session based on user experience and relevant prior knowledge.

The validation design can cover the four key aspects reflecting the quality and capacities of artefacts (Fischer *et al.*, 2012). Therefore, the interview also focuses on the design of probes follow the four key

aspects (Table 7-1). In association with the context of this research, the four key aspects and their relevant explanation will be described as follows.

Table 7-1 Four aspects of validation in design science research

Key Aspects	Explanation in the context of FINVID
Validity	To determine if the artefact functions and if the functions can fulfil the predefined objectives To evaluate if FINVID as well as visualisation work and if their process and components can help with users' understanding, interpretation and sense-making
Perceived usefulness	To evaluate if the efficacy, performance and reliability of a delivered artefact in a given context To evaluate if FINVID as well as visualisation work is easy to use, helping users with their information demands, and the appropriateness of achieving the users' purposes
Generalisability	To determine if the artefact is generally adaptable in different scenarios To discuss if the FINVID can be reused in a different context and served for a different purpose
Innovativeness	To determine if the artefact has further developed the prior model and reveal a different contribution toward research and practice To determine if FINVID can deliver a novel contribution to research and practice

The selected experts consist of an information system expert, a marketing expert, a project consultant, and six end users (Table 7-3). The end users further include three strategic managers in charge of general executives, marketing and finance, and two operation-level staff for the following data visualisation adaption and maintenance. The basic profile of involved experts in the review process can be found in Table 7-2 and extended profile can be found in Appendix 2.

Table 7-2 Expert Profile

User tag	Roles	Focuses	Relevant Background Information
IS_1	Information System Expert	FINVID along with its development process and components	Lectureship specialising in information system development Research scope covering system development and business analysis More than 20 years to system design and consulting experience
ME_1	Marketing Expert	The analysis capacities of market-related data and assistance toward market analysis	Professorship specialising in market research and branding More than 10 years of consulting experience
PC_1	Project consultant	Communication and presentation capacities	Visiting scholarship specialising commercial consulting, visual communication and design More than 15 years of consulting experience Key coordinator in the case study for communicating with users
EE_1	End User - Executives	Interactive functions; sub-activities for knowledge exploration and sharing	CEO Responsible for communicating with the board and investors

			MBA Background and more than 20 years work experience as senior executive and director in the soft drink industry
EM_1	End User – Marketing	Data collection, integration and modelling functions	Marketing director Responsible for market analysis
EF_1	End User – Finance	Financial data (income, costs, and risk measure) modelling and presentation	CFO Responsible for financial management, including income prediction, performance management and cost control More than 20 years of working experience as a financial director
EO_1	End User 1 – Operation	IDV development process, further development and maintenance	Market executive team leader MSc Marketing Responsible for market analysis, strategy implementation and tool selection and maintenance 8 years of experience as market executive (for implement market strategy and analysis)
EO_2	End User 2 - Operation	IDV development process, further development and maintenance	Market team MSc Digital Marketing Responsible for marketing data management, reporting and system maintenance 5 years of experience related to market analysis and operation support

The roles and focuses of different experts are described in Table 7-3.

Table 7-3 Roles and focuses of experts

User tag	Roles	Focuses
IS_1	Information System Expert	FINVID along with its development process and components
ME_1	Marketing Expert	The analysis capacities of market-related data and assistance toward market analysis
PC_1	Project consultant	Communication and presentation capacities
EE_1	End User - Executives	Interactive functions; sub-activities for knowledge exploration and sharing
EM_1	End User – Marketing	Data collection, integration and modelling functions
EF_1	End User – Finance	Financial data (income, costs, and risk measure) modelling and presentation
EO_1, EO_2	End User - Operation	IDV development process, further development and maintenance

A semi-structured interview is the dominant method in this research used to collect opinions from different experts. There two different approaches are utilised in the interview, including individual interview and group interview (Table 7-4). The individual interview main focuses on the design and development of FINVID, in terms of its designing rationales, developing considerations and deployment of different functional components. During the individual interview, detailed feedbacks related the framework structure and design can be provoked, especially from academic perspectives.

Therefore, the interview with IS expect, marketing expert and project consultant were conducted in an individual approach. On the contrary, the group interview mainly focuses on understanding the process of development and functions of the visualisation artefact. In the group environment, different users can exchange opinions and deliver a more holistic view towards the artefact as well as the development methods. Their opinion can also cover different levels from strategic to operational, and time-orientation from short-term targets to long-term objectives. Thus, the interview with end users were implemented in a group approach, for the purpose of knowing their feedback from different layers and practical perspectives.

Table 7-4 Individual and group interview and their focuses

Interview approach	Main focuses
Individual interview	To review the overall structure of FINVID and perceived contributions of each component To review the process and performance of demand fulfilment
Group interview	To understand and review the process and sub-activities of IDV development

The interview protocol follows the validation framework inspired by Fischer et al. (2012). A presentation of FINVID will be delivered to the expert panel, with the explanation of highlighted features and main steps in the procedure. IDV artefacts will also be used as an illustration for evaluating the outcome of different IDV activities. The expert evaluation will cover the following four aspects. The detailed interview guide, transcript and notes can be found in Appendix B.

- Validity of FINVID: to determine if the artefact functions and if the functions can fulfil the predefined objectives
- Perceived Usefulness of FINVID: to evaluate if the efficacy, performance and reliability of a delivered artefact in a given context
- Generalisability of FINVID: to discuss if the FINVID can be reused in a different context and served for a different purpose
- Innovativeness of FINVID: to determine if the artefact has further developed the prior model and reveal a different contribution toward research and practice

7.7 Validation of Results

The results of validation will be discussed from four important aspects: validity, utility, generalisability and innovativeness.

7.7.3 Validity

Validity evaluates if the artefact can deliver the required functions and reach the predefined objectives in design science research (Gregor and Hevner, 2013). Therefore, in this study, the validity of FINVID has been evaluated on efficacy, i.e. whether it helps with users' understanding, interpretation and sense-making of dataset, with sufficient considerations of their semantic demands, interpretational purposes

and decision-making context. For the demonstration of artefact, this study incorporates the visualisation artefact from case study 2 (Global Market Selection). There are two important assessment in validity evaluation. Firstly, the experts had an overview of IDV and verified if the all steps and mechanisms were clearly stated. Secondly, the artefact was presented to the experts and it allowed them to interact with the artefact in a given content. Their feedbacks focus on if the artefact has an impact on their understanding, interpretation and sense-making.

After assessing the steps and mechanisms, both the expert with information system research background and the expert with marketing research background agreed that IDV with specific steps and mechanisms offers a set clear guidelines for data visualisation development, which can function well in a real work scenario. The information systems expert (IS_1) comments that "FINVID presents a set of guidelines for facilitating the communication and collaboration between visualisation users and developers. It not only portrays the abductive process of IDV development for continuously engaging participants, but also tells the specific sub-activities on each step which can be followed and implemented by other users". One of operational-level staff (EO_1) also agrees with the applicability of IDV in their work scenario of data analysis and reporting: "the process and sub-activities make sense to us. It reveals the fact that users might get further requirements when analysing data via visualisation. Therefore, our development team can use FINVID to follow up their changing requirements and developing interactive functions based on FINVID sub-activities. I think FINVID is a valid method for us to further develop our visual reporting system in the following stages".

In addition, the experts found FINVID can appropriately fit both the research track of visualisation process and the reasoning process in business scenarios for assisting users to understand data. Different from the visualisation framework from the prior research, FINVID clearly states each steps and associated mechanisms of assisting the development of visualisation, which can be regarded as an important step forward to incorporate the information of users' semantic demands, interpretation purposes and decision-making context in the process of visualisation development. Data visualisation is no longer a one-off artefact development, but a process with continuous improvement mechanism. From practitioners' perspective, FINVID fulfils the gap in the scenario where a company purchases a database from an external consulting company and has an unclear process and unmatched tools to develop visualisation for interpretation and communication. FINVID, particularly, emphasises the importance of abductive process of developing data visualisation which allows for sufficient time to reveal and collect users' diverse demands layer=by-layer, which eventually enable the visualisation artefact to be become understandable, purposeful and appropriate to the context. A user (EE_1) comments, "different from the linear process where we need to list all specific request at the beginning, abductive reason processing is more appropriate to my situation since I might find new question when interacting with IDV. It gives a sense that I can explore the data and find valuable information and update my knowledge". This is echoed by ME_1 who states that "FINVID can enable users to interpret

data from different perspectives as well as deep their insight via the iterative process. The sub-activities of involving different experts, like myself, can help with further discovering users' information demands and sharing knowledge for users to make sense of data. This is different from the prior framework merely focusing on the visualisation techniques; FINVID pinpoints the collaboration among different participants."

However, the experts also offer a suggestion for further improving the validity. Based on the current version of the artefact, most of the work refining and updating users' demand input are conducted in a human-based manual pattern. It often requires a consulting session to go through the main functions on the visualisation, to collect feedbacks from the 'think aloud' approach, and then to further modify the visualisation afterwards. The suggestion is that if Artificial Intelligence (AI), especially Deep Learning Algorithms, can be incorporated to monitor the users' interaction with the visualisation, collecting the users' oral or written feedbacks, and identifying the key requirements. It can speed up the process of upgrading the visualisation during the interactive loop and let the visualisation artefact directly respond to a wide range of user requirement (both arranged and unarranged). An expert (IS_1) points out that "the application of FINVID relies on people, since there are still lots of manual work, such as documenting feedbacks, organising workshops and consulting interview. Therefore, the performance and outcome of FINVID might dependent on the key people who lead the project implementation. I think it might be easier to be implemented and maintained with a certain quality standard if the process can be automated". In addition, a user (EO_2) comments "FINVID helped with developing a very vital artefact. But if AI capacities can be incorporated to automate the feedback recording and analysis in FINVID, we will be able to involve more users in contributing their requests, views and knowledge".

7.7.4 Utility

Utility can be regarded as a key measure on the stage of artefact evaluation in the paradigm of design science. Since the FINVID is developed with the following design science approach, the perceived usefulness will be evaluated based on the expert review. Experts are expected to comment to FINVID based on the relevant experience and justify to what extents where IDV can help with the users' understanding, interpretation and sense-making. There are various criteria applied to the evaluation of usefulness. Hevner *et al.* (2004) measures usefulness as the efficacy of an artefact to deliver its required performances in a real user scenario. Utiltiy further consists of efficacy, performance and reliability of a developed artefact, coming from the criteria proposed by Venable, Pries-Heje and Baskerville (2016). Therefore, in this research, the evaluation of perceived usefulness is based on the three important measures, including ease of use, degree of perceived performance and appropriateness of solution.

Firstly, for the evaluation of usability, this research mainly focuses on the responses related to the ease of use when users were reviewing FINVID and were engaged with the visualisation artefact. In this part, the evaluation consists of two sections. The first section evaluates if users can understand and act on

process description, mechanism description and the guidelines for developing interactive visualisation. The second section evaluates if users feel at ease interacting with visualisation artefact and discover the potential barriers preventing them from being engaged in the interaction session. A user (PC_1) comments, “the description of six steps of abductive reasoning process makes FINIVD easy to understand and follow. With the aid of norm specification and sub-activities, I think it is also easy to involve other users for trying the visualisation artefacts, posting their information demands, and participating into discussion” Another user (EM_1) made a similar comment that “from a user perspective of view, the specifications of sub-activities in each step of FINVID helps a lot of understanding and participating into the visualisation development process and contributing the final deliverable. It includes when we should participate, where we should make comments and explanation, and how we can make further requirements and interpretation”.

Secondly, for the evaluation of performance, this research provokes users to evaluate to what extent FINVID can help with users’ understanding, interpretation and sense-making of dataset. It also probes users to point to/point out one or more specific steps or mechanisms which can effectively support their according actions. Overall, all participated experts agreed compared with the traditional methods, FINVID can help with users to establish a quick understanding of dataset, to interpret the data pattern with incorporation of different purposes, and to make sense of data via iterative investigation and consultation. Since IDV adapts abductive reasoning process, interactive and participative activities and formal development procedure with the mapped mechanisms, it can offer a considerable integrated guideline and toolsets for users to go through the lifecycle of data sense-making. To be specific, the experts made comments on different parts of FINVID and evaluated to what extent they recognised the contribution toward their sense-making activities. For the abductive reasoning process, the user (EE_1) comments, “the development cycles enable me to post further requirements based on the observation of visualisation. I can develop our interpretation of datasets and build up my knowledge in each cycle”. As for interactive and participative activities design, one user (EO_1) comments that “the norm specification is very helpful for documenting users’ requirements. Especially when the requirements start to pile up and more interactive function are demanded during the development cycles, norms specification helps the develop to understand different components of requirements and mapped them to different sub-activities of visualisation development based on the norm categories”. As for the formal development procedure, expert (IS_1) comments, “the abductive process and its associated sub-activities in FINVID are effective to developing a visualisation product which can respond to users’ information demands, interpretation purposes and sense-making of datasets in a given context”.

Thirdly, the evaluation of appropriateness focuses on if FINVID as well as the developed artefact can actually contribute to users’ sense-making activities in a real scenario. Therefore, for this evaluation, the experts were invited to interact with the artefact in a given context. The contextual information from the case study was used in this evaluation. As a result, all experts confirm that the IDV is appropriate

for data sense-making by gradually discovering users' information demands and continuous incorporating contextual information for facilitating the communication. They also can point out that the appropriateness of IDV is not only constrained in the scenario of global market analysis, but can be applied a wide range of business-related data analysis cases, since it offers not only the process with guided steps, but also portrays the activities for developing interactive function and enabling users' participation. In particular, the formal procedure with the mapped development mechanisms allows users to develop their own visualisation with concrete guidance and methods. Expert (ME_1) comments, "FINVID is appropriate for facilitating the visualisation development, based on my experience in the marketing intelligence case study. It draws attention to the involvement of different users and input of expert knowledge. It helps users to acquire and develop new knowledge via the sub-activities of highlighting, interpreting, refining and acting upon findings". Another user (EF_1) made a further comment: "FINVID is very appropriate on developing a visualisation responding to my requirements. It enables me to further develop my requirements during the development cycle, since I was gradually figuring out which financial indicate is more suitable for measuring sale potentials".

7.7.5 Generalisability

The evaluation of generalisability focuses on if the generic nature of a developed artefact can be easily adapted and utilised in a wider range of scenarios (Venable, Pries-Heje and Baskerville, 2016). Overall, the FINVID is constructed for the generic issues which occurred during the process of data visualisation development. Although a visualisation artefact was developed in the context of global market selection, the abductive process, interactive and participative activities and formal procedure with mapped mechanisms should be able to transfer to different scenarios and domain for serving different analytic purposes. Therefore, this part of evaluation aims to guide experts to comment on the potential where FINVID can extend its utilisation in different situations. The expert review consists of two sections: genericity of FINVID and transferability of FINVID.

Firstly, for the genericity of FINVID, the evaluation aims to let experts review if the FINVID is designed for resolving the generic issues of data visualisation development, instead of merely relying on a specific context. Based the expert's feedback, a consensus was generated by the participating experts that the framework can be regarded as a generic solution. The reason for the consensus is that the focus of FINVID is not to solve a specific problem or rely on a specific context, software or work process, although it was developed and polished in an illustrative case study. Its abductive reason process fits the generic knowledge discovery process with a combination of inductive and deductive thinking. For the developed artefact, it is demonstrated based on Tableau software, but the framework with procedures, activities and mechanisms can be applied to another software, such as Power BI or Google Chart. The expert (IS_1) comments, "FINVID constitutes a general method of developing IDV. Although in the demonstration it is applied on the Tableau platform, it does not rely on a particular

software function. The abductive process and sub-activities can be adapted on other platforms as well". User (EO_1) expresses a similar comment, "we currently adapting Power BI for analysis and reporting. FINVID can fit to the IDV development via those tools, like adapting abductive process for acquiring and responding users' requirements of updating marking/sales data and using sub-activities for developing interactive function and navigations for assisting interactive data exploration".

Secondly, the experts reviewed the transferability of FINVID and discussed if the IDV and its according components can be reused in other scenarios. Generally, the abductive process, interactive and participative activities design, and procedure can fit other business scenarios, such as social media marketing content analysis. However, it is also noted that the frequency and application of interactive and participative activities may vary based on the question setting, since for some questions in social media marketing content might have more dimensions as well as different sequence of discovering users' demands. Also, some minor change might occur on the mechanisms along with development procedure, since some specific questions, chart selection and interaction design may be different based on the user context. User (PC_1) comments, "I believe FINVID can be adapted into different business scenario of developing IDV for making sense of data. Minor modifications might be necessary to make IDV fit users' purposes and preferences. For example, if users were very clear of their requirements and hypotheses, they might expect more explanatory visual representation of datasets instead of interactive functions for data exploration".

7.7.6 Innovativeness

The evaluation of innovativeness aims to recognise the novel contributions that the FINVID makes toward research and practice. It consists of two sections: evaluation of research innovation and practical innovation. For the research innovation, the review mainly concentrates on if the FINVID offers any methods and techniques to further develop knowledge of interactive data visualisation. For practical innovation, the review mainly focuses on if FINVID can help with the further application of data visualisation with a different approach compared with other methods.

Firstly, as for the research innovation, the participating experts agreed that the FINVID offers a holistic view as well as an integrated approach to develop data visualisation with organised interactive functions. It incorporates the abductive reasoning process which recognised the function of development cycles in furthering developing users' understanding of dataset and further addressing their information demands based on the updated purposes and decision-making context. Expert (IS_1) comments, "although acquiring users' requirements for developing IDV is not new, FINVID is responding to the challenge of addressing a complex demand in norm specification and categories. As a structured approach, norms enable the development team to map the techniques to deliver the right information, align with right purposes and respond to the right context". In addition, it connects well the process with a set of mechanisms of data visualisation development, including requirement articulation, diagram

mapping, interactive function mapping, navigation design and storyline construction. Although the mechanism has been separately developed in the prior research, it is necessary to conduct a research to integrate them into a shared view, and guide users with a well-organised procedure. The user (EM_1) comments that "different from prior methods we used before (which) mainly focus on using different techniques of developing visualisation, FINVID presents a process where all users can work together, such as making demands clearly, inputting knowledge for sense-making and mapping requirements to the suitable techniques. Therefore, we found the final product can better fulfil our demands and help us explore and obtain new knowledge".

Secondly, from the perspective of practical innovation, the expert reviewed the FINVID in terms of its novel contributions to the end users to solve the practical problems. In FINVID, the guidance of abductive process and major steps, the measure, guidance and objectives of interactive and participative activities, and development procedure with mapped mechanisms, all contribute to improving the efficacy of users' understanding, interpretation and sense-making of dataset. Even though some of the components were well-developed in the prior studies in both academic research or industrial white papers, FINVID categorises the different components and integrates them together as a formal procedure which the users can follow to further develop an interactive data visualisation in different scenarios. A user comments, "compared with the prior experience of using visualisation, FINVID offers an integrated solution associating visualisation design principle, visualisation techniques, interactive functions and narrative skills. In addition, its sub-activities make different visualisation components work toward fulfilling users' demands, like making sense of datasets and exploring new knowledge".

7.8 Implications of FINVID in the Case Study of Global Marketing Selection

IDV has been utilised and refined in the case study of global market selection matrix. Following the preliminary procedure, this research produced a series of artefacts of data visualisation that were used to address to users' demands in the given context. The selected context is that an energy drink company needs to give an overview of the global energy drink market and construct a report with interactive data visualisation to present to the investor groups to reveal its global market selection as well as development strategy. Different from prior methods with a waterfall style process, FINVID recognise the necessity of knowledge development during the process of data visualisation development. This means that when users are viewing the visualisation, they will gradually discover new issues, further address their interpretation purposes and contextual pressure for communication. FINVID adapts the abductive reasoning process allowing them iteratively to address their demands and input information, and to enhance the participation of users, designers, consultants and experts to aid understanding, interpretation and sense-making. It enables the final artefact to fulfil the semantic demands, interpretation purposes and communication context. In addition, based on the expert review, the results

indicate that FINVID fulfils four dominant features of design science validation: validity, utility, generality and innovativeness.

FINVID provides a holistic view of data visualisation, including the process, major steps and matched mechanisms. Instead of thinking visualisation like a "one-off" design, it should be understood as an iterative and continuous refining process. FINVID also provides an integrated view of data visualisation, including abductive process, interactive and participative activities, and a formal procedure with match mechanisms. End users should follow the abductive process for allowing users to gradually establish their understanding of datasets and address their upgraded demands during the loop. Interactive activities allow users to adjust the data visualisation settings for viewing dataset from different conditions, perspectives and assumptions. At the same time, participative activities allow users to communicate with designers and relevant experts for further provoke their interpretation demands and input more purpose-related and context-aware information. Finally, a procedure with a mapped mechanism can work as a set of guidelines for users to manage the entire visualisation toolkit along with the abductive process. The prior studies establish well the theories and practical guidance on either side but rarely map them into one view, which causes the unfitness to the practical scenarios. However, IDV provide a formal procedure to guide users to think through the abductive process of data visualisation development and offer the rationales to utilise different mechanisms on each major step.

7.9 Limitations

The expert review has reflected a few limitations of FINVID. From the prospective of validity, the FINVID has not been fully applied in a real business case to empirically test its validity. Although the overall research follows the rigid process and principles of design science with an incorporation of expert review for validation, the final version of FINVID has not been given an opportunity to a full scenario of business case. Therefore, the limitation inspires the research to test the validity to the extent to which FINVID can fulfil the users' demands based expert review. In the validation test, the participation of five end-users simulate the full process of data visualisation development as well as made evaluation of the validity of FINVID. They also expressed their confidence in further adapting FINVID in the following analysis projects. In addition, the demonstration of the visualisation artefact is based on a special tool of Tableau. To some extent, it might grow a certain level of dependency on certain software, although all of the description of FINVID procedure and mechanisms are developed for generic purposes. There is a likelihood that the users might depend on a certain function of Tableau and be unable to shift to other software. Finally, business objectives and management process might vary in the following project, which would cause the unfitness of FINVID, since the development of FINVID is based on the case scenario of global market selection. However, in the evaluation of generality, all experts agreed that IDV offers a series of generic guideline for data visualisation development which can fit into the generic side of business cases. It still, however, requires the

customisation initiated by the end-users based on their specific situation. Therefore, it can be necessary to conduct a follow-up validation evaluation to witness how IDV can be valid in the different project scenario and to what extent users can adapt it to a specific context.

From the perspective of utility, a series of challenges remains to hinder the contributions of FINVID, although it has provided a holistic view of data visualisation development and integrated view with a well-structure procedure with mapped mechanisms. Firstly, it is pointed out by the experts that FINVID needs to further incorporate automotive functions and reduce the reliance on human-oriented communication. Since the FINVID elicitation and management of users' input still largely relies on human-based consultation and "think-loud" sessions, interviewers' bias might affect the users' feedbacks, which might further cause omission of information. The think-aloud session was witnessed to be time-consuming for gathering all relevant users to participate in meetings or record feedback several times during the recognition loop of abductive process. Therefore, it is suggested that involving an AI-enabled tool might be necessary to automate the overall process, such as automatically analysing the users' potential demands based on the machine learning of interpretation pathway and inputted feedback keywords – to identify the information demands, interpretation purposes and contextual pressure based on the sequence, focus, selected themes and other interactive behaviours. In addition, training tends to be a key element which might affect the further adaption of FINVID. For the purpose of remaining the flexibility and genericity of FINVID, the development of procedure and mapped mechanisms are designed without a specific focus on a certain industry or business context. Although the generic toolset has been provided in Chapter 5 and is adapted in Chapter 6 in the scenario of global market selection, this still requires users' initiatives to incorporate their understanding of domain context and basic knowledge of data visualisation tools. The communication and consultation skills are required to discover the users' demands on the different stages of data visualisation development. Therefore, it is also key to offer training for users to have a holistic understanding of FINVID, to grow the basic sense of communication and consultation requirement for demand addressing, and to connect the FINVID with the visualisation tool in use.

From the prospective of innovativeness, there is another challenge of measuring the delivered value of innovativeness in a quantitative approach. The results from expert review have demonstrated a positive impact contributed by FINVID toward data visualisation development as well as the assistance with users' understanding, interpretation and sense-making of datasets. The innovativeness from the practical perspective is also confirmed by the end users when they were reviewing the visualisation artefact in the context of Chapter 6. However, the results remain subjective and inevitably biased, since they mainly relied on the experts and users already engaged in this research and witnessing of the development of FINVID. The participation and familiarity of the framework details might enable them generically to have a deep understanding of existing and potential innovative value of FINVID. Therefore, it is necessary to incorporate more cycles of review of FINVID with the application in a

wider range of scenarios and the engagement of fresh users for further verifying the feasibility and innovativeness of FINVID. It can also evaluate if the FINVID can guide users to make another artefact with a consistent contribution in different situation compared with its implementation in Chapter 6.

In terms of validation design, this research fully relies on the feedbacks from experts, which constitutes another limitation.

With the aid of expert review, this research intends to make use of experts' knowledge and experience to justify the extent where FINVID can assist IDV development, especially the incorporation of abductive process and sub-activities. For effectiveness, all experts are either with the related background of IDV development or from the customer side with the voice of user experience. They have also experienced the whole process of IDV development from the initial requirement collect to the final validation. Therefore, they have comprehensive understanding of IDV development under FINVID and their feedbacks are effective for identifying the advancement and drawback of FINVID. For reliability, since the feedback were collected from multiple experts in the both occasions of individual interview and group discussion, this research does not rely on the view from one expert, but integrates the various views from multiple experts in order to minimise the impacts of personal bias.

However, in contrast with expert review, the alternative approach of validating FINVID is to fully re-apply FINVID into a business case. It does not require the development team to develop a full capacity IDV under FINVID, from the initial stage of requirement engineering to the stage of operation and maintenance. It would be recommended for the researchers to conduct a field work, including following the development team meetings/workshops, observing the progress of development work, interviewing the developers, consultants, experts, and end users across different stages of IDV development. It will help the research to evaluate the FINVID on each step and measure the extent where FINVID can fit the demands of IDV development. In this research, due to the customers' business priority, FINVID has been preliminarily applied in their business cases for alternating their visualisation tools for marketing information monitoring. But they have not found an opportunity to fully apply FINVID in a whole process of IDV development.

7.10 Summary

This chapter corresponds to the third stage of research design which follows the abductive process to evaluate FINVID. It also echoes the evaluation stage of design science research, where the expert review was applied to assess the validity, perceived usefulness, generalisability and innovativeness. FINVID has been utilised in the case study of marketing intelligence development. Therefore, the users and experts involved in the IDV development process were invited into the review of FINVID. The results generally confirm that 1) FINVID is a valid method of developing IDV which clearly and appropriately provides a process and a set of guidelines; 2) The usefulness of FINVID is also agreed by experts that

FINVID is easy to follow, with a reasonable performance of managing and responding to the demands and of being appropriate to sense-making of datasets; 3) FINVID constitutes a general method, which does not rely on a certain visualisation platform and is applicable to a wide range of scenarios. 4) FINVID is an innovative solution which facilitates the collaboration of different users and the mapping visualisation of techniques with different demands.

The experts review also highlights three theoretical propositions of FINVID: 1) IDV development is an abductive process where the development cycle can help with acquiring, refining and responding to users' requirements; 2) IDV development is a norm-centric process where norm specification and categories can help manage users' requirement across the different stages of IDV development and map them with the users' requirements; 3) IDV development should enable the visualisation artefact to help with knowledge exploration where users can highlight, refine interpreting findings. They finally make decisions and configure the subsequent actions based on the findings.

8 Conclusions

This chapter has given a high-level summary of the research work presented in this thesis. This research has addressed the research problems and answered the research questions proposed in Chapter 1. As an outcome, this research has constructed the Abductive Framework for Interactive Data Visualisation Development (FINVID) as generic solution for guiding the development data visualisation. The research work originates fundamentally from the study of organisational semiotics, and the development process follows the principles of design science. This research not only constructs a framework for data visualisation development, but it also provides a set of artefacts with a further insight the academic researchers and practitioners in adapting the framework in a wider range of scenarios. The outcomes and contributions of each chapter to the overall research aim and objectives will be discussed in this chapter, followed by the suggestions of advancing this research in the future.

8.6 Concluding Remarks

Chapter 1 discusses the research background, motivation, aim and objectives. The research questions were identified from other theoretical and practical perspectives. From a theoretical perspective, the research identifies the necessity of establishing an integrated framework for guiding the development of interactive visualisation, including process, sub-activities and artefacts. In addition, this research also recognises the significance of adapting logical reasoning process into the IDV development for the purposes of identifying and fulfilling the demands via the collaboration between producers and users. This research focuses on developing a generally applicable framework for IDV development and incorporates two specific case studies for exploratory study and illustration. From a practical perspective, this research identifies the necessity of incorporating IDV approaches in the scenario of charity reporting, for the purposes of enhancing their accountability and information transparency toward a wide range of stakeholders. This research also identifies the similar necessity in the scenario of marketing intelligence where incorporating IDV can help MI adapt to the users dynamic and developing demands. Therefore, the aforementioned scenarios reveal an unprecedented exploration where IDV development should not only depend on visualisation techniques, but should also require an integrated framework to incorporate development process, sub-activities of IDV development and considerations of both social and technical factors.

Chapter 2 reviews the literature related to the definition of data visualisation as well as the prior models of visualisation and visual analytics in order to answer the research questions. To be specific, the reviewed literature includes the definition and development data visualisation, organisational semiotics as theoretical foundation, reasoning process in the context of data visualisation. The review of organisational semiotics essentially establishes the theoretical knowledge of developing IDV, including semiosis for understanding the process of making sense of signs, semiotic ladders to understanding of sense-making process on technical and social layers, requirement engineering framework for eliciting,

documenting and managing stakeholders' requirements, and norm for articulating requirements with considerations of content, purpose and context. The discovery of prior literature in this chapter indicates three assumptions of IDV development that IDV development can be viewed as: a combination of process and artefact, an integration of objectivity and subjectivity, or a fusion of data and interpretation. It also further suggests three propositions for the construction of FINVID in the following chapters: 1) IDV development as a norm-centric process; 2) IDV development embedded with an abductive reasoning process; 3) IDV development serving for knowledge exploration.

Chapter 3 covers the discussion of research paradigm, approaches, methods and techniques in the information system research and the selection of appropriate methodology for researching IDV development in a context of socio-technical systems. This chapter also highlights the importance of adaption abduction process as main guideline for research development, with a comparison of deduction and induction. Based on the discussion of research methodology, the overall research design adapts interpretivism as the research paradigm due to the nature of this research in constructing a subjective understanding of IDV development from developers' and users' perspective. Abductive reasoning process has been adapted in this research to continuously refine the propositions while engaging with different case studies. Design science research and case study approaches are incorporated in this research, where the exploratory study for further constructing and refining theoretical propositions and the illustrative case study is to validate and further develop the conceptual framework.

Chapter 4 describes the implementation of the initial stage of abductive reasoning process where the initial real-life observation is utilised for examining and refining the initial propositions from the literature. At this stage, an exploratory case study was conducted with a scenario of developing an IDV prototype of UK charity report. Informed by design science research and case study techniques for collecting, 10 participants were involved for interacting and reviewing the IDV artefact for the purposes of examining the preliminary propositions. A visualisation has been constructed in the scenario where users intend to understand and analyse the financial and operational status of charities and then decide if it is worthy to support. The data for visualisation construction, including charity data and initial users' requirements, were collected from the Charity Commission and relevant charity report research. A 4-step of linear IDV development approach has been utilised, including requirement articulation, data collection, visual representation programming and interaction design. Users' feedbacks were collected via think-aloud sessions for examining and further developing the preliminary proposition. As a result, three propositions were valid and further developed based on the observation of users' interaction as well as their feedback, which can be further inputted to Chapter 5 for the construction of conceptual framework.

Chapter 5 portrays the conceptual framework of IDV development, named as Abductive Framework of Developing Interactive Data Visualisation (FINVID). It corresponds to the step in the design science

research, which develops a solution towards designing problem of IDV development. Abductive reasoning process is applied to lead the process of IDV development. This chapter elaborates the six stages of IDV development, which consist of: 1) capturing and organising participants' prior knowledge for initial visualisation construction; 2) establishing the initial propositions based on the initial observation; 3) matching and updating information to the prior knowledge; 4) identifying the gaps; 5) addressing further questions; 6) refining/generating new knowledge for guiding the following actions. The construction of FINVID also echoes the refined propositions from Chapter 4: 1) norm-centric process; 2) abductive reasoning approach; 3) serving for knowledge exploration. As an outcome, this chapter provides a conceptual framework (FINVID) which is further applied and validated in the following case study (Chapter 6).

Chapter 6 utilises FINIVD in the case study of developing a marketing intelligence for global market selection. In this chapter, real-life observation (incl. user feedback) contributes to the validation and finalisation of FINVID. Six steps of FINVID were fully implemented in this case study scenario. During the process, users' requirements were articulated via norm specification and further mapped into seven sub-activities of IDV development, including collecting data, establishing model, selecting visual representation, designing interaction, setting navigation and constructing story line. Corresponding to three propositions, the application of FINVID in this chapter demonstrates the validity of adapting abductive reasoning process in scenarios of IDV development, the contributions of incorporating norm during the development process, and the necessity of knowledge exploration in IDV.

Chapter 7 mainly focuses on the validation of the abductive framework of IDV based on readers' and experts' feedbacks. A semi-structured interview is utilised to collect feedbacks, which covers the four aspects of abductive framework of IDV, including validity, generalisability, usefulness and innovativeness. In addition, the chapter discusses the implication and limitations of the Abductive Framework of IDV. Based on the result, FINVID has addressed the research questions and three main propositions have been further validated and refined. IDV development process can be portrayed as an abductive reasoning process where the in-depth users' requirements can be elicited with the aid of those users' engagement and interaction. Norm specification as an important carrier of users' requirements across different stages of IDV development for acquiring and communicating users' requirements. IDV development not only constructs a visualisation artefact for representing data, but also facilitates the collaboration among users, developers and experts for embedded knowledge exploration functions in IDV. Chapter 8 concludes the research with concluding remarks of each chapter, contributions from theoretical, practical and methodological perspectives, research limitations and suggestion to future work.

This research has constructed Abductive Framework for Interactive Data Visualisation Development (FINVID) taking theoretical inspiration from organisational semiotics. This research derives an

integrated method of developing IDV, which specification of six steps of abductive reasoning process and 6 sub-activities of IDV development. It offers a new solution for solving the IDV development issues to work scenarios. In addition, three key propositions of IDV development stemming FINVID were validated and refined in this research, which can further the understanding of IDV development on the theoretical aspect.

8.7 Contributions

This research has proposed an integrated framework of developing IDV with specification of process, sub-activities and mapped techniques. This research highlights the importance of incorporating abductive reasoning process, norm specification and knowledge exploration in the process of developing IDV. The specific research contributions are discussed in the following sub-chapters on the theoretical, practical and methodological aspects.

8.7.3 Theoretical Contributions

As regards the theoretical aspect, this research has addressed the theoretical issue via further developing the statement of 'data visualisation as a process' (Liu and Tan, 2015) to three key theoretical propositions, for the purpose of facilitating the sense-making of dataset in the context of IDV. Firstly, IDV development is a norm-centric process where norms can be utilised as an important carrier for eliciting, documenting, validating and managing users' requirements, especially when users continuously update the requirements during the iterative observation and interaction with IDV. Secondly, IDV development can be structured as an abductive reasoning process where users can bring their prior understanding to IDV development, address their requests while engaging with IDV and update their understanding after interacting with IDV. Compared with the traditional linear process, the iterative nature of abductive reason process enables users to address their demands from different perspectives, including the information needs (semantic), purposes (pragmatic) and context (social). Thirdly, the IDV development enables the IDV artefact to facilitate knowledge exploration. IDV development is not only to produce an artefact, but also enables users to explore new knowledge when engaging in IDV development. Knowledge input from experts and analysts are incorporated during the IDV development process to help users in understanding the meaning of data patterns, interpreting the findings and puzzles with their specific purposes, and suggesting conclusions and actions based on the results. Thus, three key propositions in this research furthers the theoretical understanding of IDV development which enables users to make sense of dataset via IDV artefact.

This research has adapted abductive reasoning process in FINVID for IDV development and highlighted its importance and contributions. Based on the prior literature, visualisation development mainly focuses on the technical aspect(s), and suffers from an insufficient understanding of users' requirements, especially establishing a holistic understanding consisting of information needs, purposes and context. It therefore means that users can hardly explore the visualisation or make sense of dataset

via visualisation. Abductive reasoning process enables users to bring their initial requirement and prior knowledge to participate into the initial view of IDV, and then continuously addresses the requirement during the process of exploring the visualisation. At the same time, IDV developers can also build up their understanding of users' demands and further develop the IDV artefact for fulfilling their updating demands. Due to the iterative nature of abductive reasoning process, the developers can enable the IDV to respond to the users' demand on semantic level (what is the meaning of dataset and patterns), pragmatic level (what is the interpretation purpose) and social world (what are the suggested actions in a certain context).

This research has advanced the specific design and deployment of mechanisms in each step of the process of data visualisation development. This is different from the conceptual frameworks and the model of visualisation from the prior research, which merely describes the major steps of visualisation reading and construction without mapping to the activities and techniques. FINVID outlines six major steps of visualisation development with a highlight of the iterative nature of abduction. It also describes a series of sub-activities for each step, including think-aloud sessions for real-time feedback, consulting workshop for expert's participation and knowledge input, and six sub-activities for mapping the users' demand with IDV development activities. To some extent, FINVID helps bridge the theoretical part with the practical reality by constructing an integrated view of reasoning process, sub-activities for development, social activities for capturing and responding to users' demands, and associating the requirements with visualisation design principles, charts and techniques.

8.7.4 Methodological Contributions

On the methodological aspect, this research offers a method of developing IDV with specification of development process, norms specification, sub-activities of IDV development and mapped visualisation principles and techniques.

Firstly, this research has incorporated norms in IDV development process as an important carrier for requirement management. This is different from the narrative description of user's requirement which might cause ambiguous and contradictory understanding between users and developers. Also, without a structured format, developers found it hard to identify the corresponding information for requirement content, purposes and context, and therefore the produced IDV artefact might not be able to fulfil users' demands. As a result, norm specification has been incorporated in IDV development process of FINVID, which helps elicit both social and technical aspects of users' demands, and then can be further used as guideline to justify the design and selection of interactive functions which enables users to explore the dataset. To be specific, the users' requirements generated in each development loop were initially elicited and documented in the narrative format during the consulting meeting. With the participation of experts and analysts, all requirements can be further articulated in the norm specification with five main aspects (context, condition, agent, denotation and action). Then the norms can be further

categorised into five categories (perceptual, cognitive, evaluative, behavioural and denotative) which can be mapped to different sub-activities of IDV development. As a result, the incorporation of norms helps connect all steps during the IDV development, and ensure that all activities of requirement management, visualisation development, interpretation and sense-making serve the consistent information needs, purposes and context.

Secondly, this research has specified the sub-activities for each step of IDV development process in FINVID. As is discussed in sub-chapter 9.2.1, IDV development process consists of six major steps with a development loop for iteratively acquiring and responding different sub-activities. Different sub-activities have been assigned to each step of IDV development. To be specific, stakeholder onion and user persona can be utilised in the step 1 for acquiring the initial requirements of major users, which can be further articulated into norm specifications for the initial loop of IDV development. Think-aloud sessions where users can give feedback and address new requests while interacting with IDV can be employed in steps 2 and 5 for the purpose of identifying the key findings and major puzzles users encountered during the interaction. In steps 3 and 4, a consulting workshop can be scheduled for making further interpretations with associated knowledge towards each proposition of findings and puzzles. With the input of experts' knowledge, they can be further transferred to conclusions and new hypothesis for further actions. In step 5, the categorised norms can be mapped into the six sub-activities for constructing virtualisation, including collecting data, establishing model, selecting visual representation, designing interaction, setting navigation, and constructing story line.

8.7.5 Practical Contributions

On the practical aspect, this research has contributed an innovative methodology (FINVID) to develop IDV in the business context. The initial thoughts of FINVID have been reviewed in the case study of charity report and have been validated in the case study of marketing intelligence. Based on the users' and experts' feedback, the practical contributions of FINVID can be summarised as follows.

Firstly, different from the visualisation models reviewed in Chapter 2, which either merely focus on the technical aspect of visualisation programming or portray the main steps without provide specific guidance for development, FINVID offers an integrated solution where the developers and users can use to develop an IDV in a certain business context. FINVID adapts the abductive reasoning process for iteratively acquiring users' requirement from different aspects, like information needs (what would you like to know?), purposes (why do you want to know it?) and context (what ways would you like the results to be communicated?). In addition, there are six specific steps of developing IDV in the abductive reasoning process. For each step, FINVID specifies the usage of norms for users' requirement management, such articulating requirements to norm specification, categorising norm specification based on their purposes and functions, and finally incorporating norm specifications to sub-activities of IDV development. In the case study of marketing intelligence, users' initial requirements can be

captured with the aid of stakeholder analysis and user persona, which help producers establish a basic understating the context of IDV development. Four development loops enable developers to further their understanding of users' demands, from data collection (what data are they interested in?) to story line construction (what is the context, content and conclusions presented in IDV?). Therefore, referring to users' feedback, compared with other descriptions of visualisation process, FINVID clearly states the process of IDV development with specific guidance, measures and template on each step, which can help developers to apply it to a certain project scenario.

Secondly, FINVID reflects a general method of IDV development, since it is not bound to a specific software platform. Although Tableau has been employed as the dominant software in the demonstration and prototypes of case studies, FINVID is a generic framework informing the process, norms, sub-activities and techniques of IDV development. As a result, the following developers and analysts can apply FINVID to a wide range of business scenarios, serving different users with different purposes. All guidance and templates developed in FINVID can be filled with different contents based on users' requirements, but norm-centric approach for requirement management and abductive reasoning process can help with IDV development. The develop loop can help developer gradually identify users' diverse and updated demands, covering information needs, interpretation purposes and sense-making context. In addition, the utilisation of norm-based approach can enable visualisation design to understand the users' requirement from various aspects, such as social and technical, which will allow the visual presentation to deliver the right information to the right people, the right context and to serve the right purpose. In particular, in the case studies, the framework of interactive data visualisation will be applied to the scenarios of market selection, which helps users to quickly compare different markets based on their attractiveness indicators and find the most suitable market to launch their new products. It will also be applied to the scenarios of charity reporting practices, which empower different readers to evaluate the performance of charities based on their criteria.

8.8 Limitations

The evaluation of this research design has revealed the following limitations.

Firstly, FINVID merely adapts an abductive process, which assumes that users generically bring their prior knowledge to the observation, address new questions and refine their knowledge with the iterative observation and interaction. To some extents, the application of inductive and deductive reasoning approaches has been insufficiently discovered. However, iterative nature of abductive reasoning might not be accepted for some users due to the heavy input of time and manpower. In the case study of marketing intelligence development, the IDV development experienced four loops of development and refinement, which requires frequent engagement of users, experts, analysts and developers. If under time pressure, users might be more likely adapt the deductive approach where a few hypotheses can be specifically generated based on the prior experience and where they expect to examine their hypotheses

by observing the data pattern demonstrated in IDV. Therefore, it might require IDV to be more explanatory toward users' hypotheses and questions with less motive for participating in interactions and collaboration with developers.

Secondly, this research does not have an opportunity to fully apply FINVID into a complete user case. The development and application of FINVID is merely based on 2 case studies, including case study of charity report and marketing intelligence. The initial version of FINVID was derived from the case of UK charity reporting practice, and then it has been further developed in the case of based on observation of users' inputs and engagement. Although it is confirmed by the users and experts that FINVID constitutes a generic method of IDV development which can be adapted into a wide range scenario, the users' requirements might vary across different context which can further impact on the method of developing IDV. In the case study of market intelligence development, the users were very willing to be involved into the IDV development process and dedicate themselves to exploring patterns, interpretations and implied actions. Their in-house developer team committed to learn FINVID and its associated methods for further developing the IDV for the following demands of data analysis in the long run. However, for other users in different scenario, they might not possess sufficient willingness and skills for adapting FINVID. They therefore might feel FINVID tends to be overly complicated, and linear methods of data visualisation development might be able to deliver a quick view of dataset. Therefore, the perceived utility of FINVID might depend on users' context, and different users can view FINVID, and artefact(s) produced under FINVID, in different ways.

Thirdly, the adaption of FINVID might require users to team with developers, analysts and experts, to ensure that users have access to sufficient IDV development skills for understanding the sub-activities of IDV development and consulting skills for acquiring further information of users' demands, interpretation purposes and context. In FINVID, socio-technical characteristics were observed from the IDV development process. It requires the developer team to be skilled at communicating with users, especially in acquiring and refining their requirement(s) during the iterative development process. Therefore, further challenges can be addressed regarding training users and the developer team in terms of understating the abductive process, equipping with basic skills of consulting and technical knowledge of IDV development.

Fourthly, further limitations can be discussed based on the evaluation of design science research process. Design science consists of three major steps, including (1) initial research definition and design, (2) observation and construction, and (3) evaluation and refinement.

In the first step, this research has identified the prominent issues based on prior studies. It has pinpointed that although the techniques of IDV development has been increasingly matured and available to use, insufficient guideline the methods to organising and informing the IDV development undermines the performance of IDV e.g. accurately reflecting and fulfilling users' demands. The review also covers the

relevant studies related to two case study scenarios, including the issues in UK charity visualisation report and global marketing intelligence. However, since design science method starts with a being aware of a practical issue, merely relying on the literature review, as a secondary data source, might not sufficiently in-depth information for raising awareness of the practical issue. It might have prevented from developing a comprehensive understanding of the practical issue, including its potential causes, development process and various effects. Therefore, it would be more appropriate to incorporate different approach to collecting inputs for discovering the practical issue.

In the second step, this research has incorporated two case studies for developing and applying FINVID. The case study 1 was applied for preliminary development of theoretical propositions of IDV development and construct the initial version of FINVID based on users' feedbacks. Then case study 2 was utilised to apply and refine FINVID during the process of developing an IDV artefact. However, since FINVID is designed as generic framework to inform IDV development which is supposed to be generally applicable in a wide range of scenarios, the inputs from merely two cases might not be able to offer sufficient information to guide the construction of FINVID. In other words, it is likely for FINVID to solely fit to the specific scenario of two case studies. Therefore, it would be more beneficial to involve multiple case scenarios when developing and refining FINVID, since the various situations will pinpoint more elements which should be considered in FINVID, such as different decision-making contexts.

In the third step, this research fully relies on the expert review for validating FINVID from four aspects, including validity, utility, generalisability and innovativeness. Although some insightful feedback and constructive suggestions based on experts' knowledge and experience has helped the refinement of FINVID, their limitations in knowledge and experience as well as their personal bias might affect the overall quality of validation. Therefore, it would be more accurate to validate FINVID in a complete IDV development project. It will offer an opportunity to observe the contributions of FINVID in each single step of IDV development.

8.9 Future Work

Based on the limitations identified in the research design and FINVID, there are following suggestions for the following researches.

Firstly, other than abductive reasoning process, deductive and inductive reasoning process can be incorporated in FINVID. For the six steps of FINVID, steps 1 and 2 reflect the characteristics of deductive reasoning approach where users bring their prior knowledge and even hypotheses to the initial observation of IDV. They then examine their hypotheses based on the observation of IDV with results of acceptance and rejection. Steps 3 and 4 reflect the characteristics of inductive reasoning approach; users might generate a new understanding based on the observation on IDV. Therefore, the following

research might consider further explaining the deduction and induction process in FINVID and exploring the potential of adapting FINVID to deductive and inductive research approaches.

Secondly, it is encouraged for future research to extend the application of FINVID in different user scenario for extending the generalisability of this research. As is discussed in the limitation part, the perceived utility might depend on the user context. Therefore, applying FINVID in various cases might help with refining the FINVID, its sub-activities and associated techniques. In addition, more specific measures can be developed for facilitating interaction and feedback sessions during the development loop. In this research, most of the table, interview outline and templates were developed and refined based on literature review and two case studies. If there were more application of FINVID in the future research, more useful tools and techniques would be found and incorporated to enhance the functions and adaptability of FINVID.

Third, it is necessary to further develop FINVID to be an integrated toolkit via automating the process with embedment AI capacity. Since the most of the required elicitation, documentation, validation and articulation were conducted in a manual pattern, where the research sat beside the users during the think-aloud session for recording their comments, feedback and requests, it consumed a large amount of human efforts and time to complete all documents for leading IDV development. In addition to the research, the experts frequently participated in a consulting workshop for inputting their knowledge and helping with integration and suggestion. Therefore, it can be suggested to facilitate FINVID with an automated and integrated toolkit which automatically records and analyses the activities, comments and questions when users are interacting with IDV during the think-aloud sessions. AI can be used to monitor the interactions, analyse and understand users' interpretation patterns and preferences. It can then recommend different navigation path to them for focusing on a certain data pattern and to match with experts' explanation for helping users make sense of data and to configure the following actions.

Finally, the application of design science research can be further improved in the following research. The suggestions can be addressed based on three major steps of design science research.

In the first step, instead of relying on desk-based research, more various inputs need to be integrated. For example, interviewing industrial professionals might be able to provide an updated view of the current issues in the industry with in-depth details. It can then offer a more comprehensive understanding for the research to perceive the issues from different aspects, including its causes, evolution process and impacts to the businesses. It can also provide a more solid ground to propose the initial solution based on the principles of design science.

In the second step, more case studies from different user scenarios needs to be incorporated. Since design science involve an iterative process of developing and refining the solution, inputs and feedbacks from different user scenario will help enhance the generalisability of solution, instead of being locked in a specific scenario. It is recommended for the following research to select at least three case studies,

define the sequence of case studies and their difference focuses. For examples, the first case study can be used to examine the steps related to requirement engineering; the second case study can be used to examine the steps of iterative development (loop) ; the final case study can focus more on communicate the outcome with users via the refining and generating new knowledge.

Other than abduction in design science, inspired by March (1983) and Roozenburg and Eekels (1995), induction and deduction can be included in the following studies. With deductive research approach, the expected outcome of FINVID can be set as hypotheses, and they can be examined with mean of user survey. It can help measure generalisability and external validity of FINVID in a wider range of user scenarios. With inductive research approach, a long-term field work can be considered to gain an insight of FINVID utilisation in a business case. The researcher can be emerged in the case situation and participate in the complete process of IDV development. Then the researcher can identify the contributions and drawback of FINVID in each step of IDV development.

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Appendix A

Research Ethics Committee

Consent Form

Mr. Qi Li

Doctoral Researcher

Email: q.li5@reading.ac.uk

Mobile: [redacted]

I am a PhD student at the Henley Business School, University of Reading. My research focus is to construct a methodology to guide the development of interactive data visualisation. You are invited to attend a think aloud session where assuming you are potential individual donor of charities, you need to obtain information about a charity from the data visualisation and then justify if you would like to donate to them. You will interact (by mouse click) with a data visualisation application and explain your intentions to view different charts (e.g. why do you want to do it), perceived information (e.g. what have you read from this chart), and other thoughts (e.g. do you need to address further questions after view the chart). The purpose of think aloud session to understand how a participant interacts with visualisation, including the intentions and procedure of reading through different charts, and the extent where interactive visualisation can respond to participants' information demands. After interacting with the visualisation application, you will be asked with a few more open questions related to norms, abductive reasoning process and knowledge exploration.

Participant's agreement

- I have had explained to me the purposes of the project and what will be required of me, and any questions I have had have been answered to my satisfaction. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.
- I understand that participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.
- I agree to the interview audio taped and the laptop screen recorded.
- This application has been reviewed by the University Research Ethics Committee and has been given a favourable ethical opinion for conduct.

- I have received a copy of this Consent Form and of the accompanying Information Sheet.

Name: ……

Company: …….

Position: ……

Date of birth: ……

Signed: ……...……

Date: ……...……

Information Sheet: Think-aloud Session Procedure

Introduction

Thank you for attending this think-aloud session. Please assume you are an individual donor of charities and you need to use the data visualisation tool to find out the information about a charity. Then you can evaluate its performance and justify if you would like to support this charity.

You can interact with the data visualisation application by using a mouse. Please try to tell what you think when viewing the chart or clinking charts for querying further information. For example, you can tell what you would like to know, why do you want to know, whether it provides sufficient information and what would like to know further. I will try guide to express your through by asking some questions when you interact with the application.

Encountering visualisation

The overview page is presented to the participant.

- How are you going to measure a charity's performance? What will be your focus?
- What can you understand from the overview page?

Constructing a proposition

Participants are invited to express their initial thought based on the observation of overview page.

- What is your impression of this charity based on the information you find from the visualisation?
- What other information would you like to view?

Exploring visualisation

Participants are allowed to use the interactive functions. They hover the click the visual representations for selecting and filtering data, hover chart for activate annotations, and connect to the narrative information.

Generating new questions

Participant can ask further questions based on the information they have obtained from the visualisation.

- As an individual donor, do you think that you have obtained sufficient information about the charity in order to justify if you would like to donate to the charity?
- If not, is there any other questions you would like to ask based on the information you gain from the visualisation?

Drawing conclusions

- What is the key information you have obtained from interacting with the visualisation?

- From your own perspective of view, how does visualisation as well as the interactive function help you obtain information about the charity?

Further questions

About norm

Norm specification used in the IDV design will be demonstrated to the participants. Participants might be invited to describe an information request, then the request can be documented in the format of norm specification for demonstration purposes.

- Compared with the describe the request in natural language, do you think using norm specification can help you address your request?

About abductive reasoning process

The concept of abductive reasoning process will be explained to the participant.

- Do you think you have followed the abductive approach to obtain the information from the visualisation? Especially adapt an iterative way of discovering information.

About knowledge exploration

- Do you think that interacting with the visualisation has helped you update your knowledge of measuring the performance of a charity?
- Is there any knowledge that you have obtained via interacting with the visualisation?

Sample Transcript and Notes

Questions	Participant's Feedback (P6)
How are you going to measure a charity's performance? What will be your focus?	If I were an individual donor, I would like to check efficiency of charity spending, like how much they have spent on charity activities in a year and what activities they spent their money.
What information can you understand from the overview page?	It shows on the bar chart the income is higher than expenditure. It means that the charity has a surplus this year. It might be a good sign that the charity can keep some fund to support the activities next year. In this year, it spent £84 million on the charity activities. It counts around 60% of its income. Since I would like to see the further breakdown of expenditure and find what is the biggest charity spending, I selected the option of "expenditure" to focus on the expenditure data. It shows a bubble chart. There are 5 categories of spending. "Your community" counts the biggest proportion, which seems like the service to support the senior community. Since I would like to know further about the charity activities, I would like to check the description of activities (hover the bubble of your community)
What is your impression of this charity based on the information you find from the visualisation?	General speaking, this charity seems to have a healthy financial status, since it saves 40% of its income to the next year. It supports a good range of charity activities, covering different aspects of senior life, such as community support, wellbeing, heath, home and pension. I do believe that it is good have a charity focusing on taking care senior citizens due to the trend of aged society.
What other information would you like to view?	I would like to know more information about the charity activities. If I can have some examples about how the charity activities helps senior people. What are the impacts on their life? Also, I would like to check the percentage of charity activities spending in the total spending. Therefore, I can compare the spending on charity activities with other management expenses.
As an individual donor, do you think that you have obtained sufficient information about the charity in order to justify if you would like to donate to the charity?	Not yet. Basically, I just viewed the proportion of major expenses, and identifies the basic categories of funded activities. It is not enough to reflect of whole picture of charity performance. I would like to read more about how the charity activities have helped people. Also, I would like to know further about its managerial efficiency. If most of money were spent on management, I will therefore not support it since its internal management and operation is not efficient enough. Most of fund may be wasted.
If not, is there any other questions you would like to ask based on the information you gain from the visualisation?	Case studies of beneficiaries Telephone services – fight against loneliness of senior citizens – how much money spent and out comes If the outcome can be quantified and compared with other charities within the same category

Compared with describing the request in natural language, do you think using norm specification can help you address your request?	More clear – to easily identify different components of information To focus on the intentions and context for interpretation Intentions and context can be categories – might not he customised one by one, since they might vary among people However, since I am not familiar with the norm specification, and its grammar rules and notations, it is very hard for me to document my requirement in the norm way
Do you think you have followed the abductive approach to obtain the information from the visualisation? Especially adapt an iterative way of discovering information.	First of all, I did not know the concept of abduction at the beginning. Based on your explanation, I do believe abduction is a generic approach for everyone to understand everything. Since it is not guarantee to obtain all information in one step, I will come out new questions after viewing the visualisation Iterative way helps a lot for me to check my understanding and ask further questions
Do you think that interacting with the visualisation has helped you update your knowledge of measuring the performance of a charity?	I think interaction is very important. For me, visualisation makes the information easier to understand, compared with reading through a big chunk of text Interview visualisation allows me to select the important data I would like to view Filter the unnecessary data and minimise the disturbance and confusion
Is there any knowledge that you have obtained via interacting with the visualisation?	However, if a charity has kept a big amount of money in its bank account, it might have raised more money than what they actually need.

Appendix B

Experts' Profile

User tag	Roles	Focuses	Relevant Background Information
IS_1	Information System Expert	FINVID along with its development process and components	Lectureship specialising in information system development Research scope covering system development and business analysis More than 20 years to system design and consulting experience
ME_1	Marketing Expert	The analysis capacities of market-related data and assistance toward market analysis	Professorship specialising in market research and branding More than 10 years of consulting experience
PC_1	Project consultant	Communication and presentation capacities	Visiting scholarship specialising commercial consulting, visual communication and design More than 15 years of consulting experience Key coordinator in the case study for communicating with users
EE_1	End User - Executives	Interactive functions; sub-activities for knowledge exploration and sharing	CEO Responsible for communicating with the board and investors MBA Background and more than 20 years work experience as senior executive and director in the soft drink industry
EM_1	End User – Marketing	Data collection, integration and modelling functions	Marketing director Responsible for market analysis
EF_1	End User – Finance	Financial data (income, costs, and risk measure) modelling and presentation	CFO Responsible for financial management, including income prediction, performance management and cost control More than 20 years of working experience as a financial director
EO_1	End User 1 – Operation	IDV development process, further development and maintenance	Market executive team leader MSc Marketing Responsible for market analysis, strategy implementation and tool selection and maintenance 8 years of experience as market executive (for implement market strategy and analysis)
EO_2	End User 2 - Operation	IDV development process, further development and maintenance	Market team MSc Digital Marketing

			Responsible for marketing data management, reporting and system maintenance 5 years of experience related to market analysis and operation support

Research Ethics Committee

Consent Form

Mr. Qi Li

Doctoral Researcher

Email: q.li5@reading.ac.uk

Mobile: [redacted]

I am a PhD student at the Henley Business School, University of Reading. My research focus is to construct an abductive framework for interactive data visualisation development (FINVID). The construction of framework was based on a case study of developing a market intelligence tool for help users to select a set of target market with the greatest profitability and growth potential. You are invited to attend the validation session where based on your experience and knowledge, you can help evaluate the validity, usefulness, generalisability and innovation of FINVID. A researcher's presentation and demonstrated of IDV artefact will be scheduled beforehand. Then you can conduct an evaluation based on the following highlighted components of FINVID.

- Three highlighted characteristics of FINVID, including norm-centric process, abductive reasoning approach and iterative nature, and knowledge exploration
- Five steps of IDV development process
- IDV artifact of global market intelligence

Participant's agreement

1. I have had explained to me the purposes of the project and what will be required of me, and any questions I have had have been answered to my satisfaction. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.
2. I understand that participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.
3. I agree to the interview audio taped.
4. This application has been reviewed by the University Research Ethics Committee and has been given a favourable ethical opinion for conduct.
5. I have received a copy of this Consent Form and of the accompanying Information Sheet.

Name: ……

Company: ……..

Position: ……

Date of birth: ……

Signed: ……...……

Date: ……...……

Information Sheet: Expert Review Interview Guide

Thank you for attending the validation meeting.

A presentation of FINVID, its highlighted features and five main steps will be delivered by the researcher.

The IDV artefact will be demonstrated in a laptop, and then the invited expert can go through the artefact with guide of the researcher.

Expert evaluation will cover the following four sections.

Section 1 Validity of FINVID

This section is mainly designed to determine if the artefact functions and if the functions can fulfil the predefined objectives and to evaluate if FINVID as well as visualisation work and if their process and components can help with users' understanding, interpretation and sense-making.

1. Do you think FINVID helps design IDV artefact, from data collection to knowledge articulation?
2. Do you think FINVID helps users better understand data, obtain information, and develop knowledge via adapting an abductive reasoning process?
3. Do you think allowing users to interact with visualisation under FINVID can better satisfy users' information needs?
4. Do you think taking account of users' intention and contextual factors under FINVID can enables the interactive function to better fit to the users' demands?

Section 2 Perceived Usefulness of FINVID

This section is mainly designed to evaluate if the efficacy, performance and reliability of a delivered artefact in a given context and to evaluate if FINVID as well as visualisation work is easy to use, helping users with their information demands, and the appropriateness of achieving the users' purposes.

1. Do you think FINVID is an appropriate method for developing IDV, including managing requirements, guiding the design of visualisation and its interactive functions, fulfilling users' demands and enabling knowledge exploration?
2. Do you think FINVID is easy to use for developing IDV?
3. Do you think five steps of FINVID is easy to understand and follow?

Section 3 Generalisability of FINVID

This section is mainly designed to discuss if the FINVID can be reused in a different context and served for a different purpose, and to discuss if the FINVID can be reused in a different context and served for a different purpose.

1. Do you think FINVID can be generally applicable in different IDV development scenarios?
2. Do you think the results and artefacts produced in the case study can be replicable in other scenarios?

Section 4 Innovativeness of FINVID

This section is designed to determine if the artefact has further developed the prior model and reveal a different contribution toward research and practice, and to determine if FINVID can deliver a novel contribution to research and practice

1. Do you think FINVID offers an innovative way to help construct an integrated solution for developing IDV? It integrates the methods of requirement engineering, procedure of visualisation development, and mechanisms of knowledge management.
2. Do you think that the iterative nature of FINVID is a creative approach to fulfil users' demands during the process of IDV development?

Sample of Transcript and Notes

Questions	PC_1
Do you think FINVID helps design IDV artefact, such as guiding data collection and visual representation design?	Yes. FINVID is a valid method to design IDV artefact. Especially it focuses on collecting users' requirements in different stages and mapping them with different tasks. For example, the initial requirements can be mainly used to collecting and selecting data and building the initial model. Then when the users are engaged in using visualisation, their further requirements can be collected for designing the interactive functions. Therefore, the users can further explore the information, such as "what-if" scenarios.
Do you think FINVID helps users better understand data, obtain information, and develop knowledge via adapting an abductive reasoning process?	Yes. Abductive reasoning process can help users create or develop new knowledge, since the users can bring their own prior understanding in the observation, continuously update their understanding via continuous observation, and finally generate new knowledge. In FINVID, unlike the traditional waterfall style method, it gives a chance for users to address and develop their demands stage by stage. Most likely, once they had the initial view of visualisation, they will come out more questions which they would like to explore in the visualisation. Also, a series of consulting sessions has been scheduled along with development process to help address their findings and further requests.
Do you think allowing users to interact with visualisation under FINVID can better satisfy users' information needs?	Yes. Compared with the static visualisation, interactive functions allow users to further address their requests to the visualisation interface. It enables users to focus on different parts of datasets, such as sort the markets by total volume or group the markets based on location. It enables users to set parameters for evaluating the market performance based on different conditions. It is very important in the market analysis, especially to estimate the market size and growth under different assumptions.
Do you think taking account of users' intention and contextual factors under FINVID can enables the interactive function to better fit to the users' demands?	Yes. I think for the same data and visualisation, different users with different intentions and under different contextual pressures might have different interpretation. Therefore, it requires visualisation to be flexible to adapt to different users' demands. In FINVID, when it selects visual representations and interactive functions, it always tries to address the questions like "why do they want to know it" for acquiring users' intentions. For the contextual pressure, it is also very important to incorporate them into IDV development, since it will determine the way users would like to display the data to reveal the story. For example, when we were developing the MAI part of visualisation, the users were under pressure given by the board and other investor to seek the market with a growth potential in the following 5-10 years. Therefore, we match the requests with an interactive function to selecting different approach of prediction as well as construct a storyline to show data from the current market situation to future trends. However, the information of intention and context might not be able to be captured at the beginning of project. Therefore, it is also necessary to use abductive reasoning process to continuously discover and understand uses' demands.
Do you think FINVID is an appropriate method for developing IDV, including managing requirements, guiding the design of visualisation and its interactive functions, fulfilling users' demands and enabling knowledge exploration?	Yes. It is an appropriate method for IDV development, since it covers the whole process of IDV development, instead of giving lots of fragmented instructions to users. Firstly, it includes a set of methods of collecting users' requirements, like collecting requirements by stages and using norms to categorise requirements by usages. Secondly, it matches different requirements to functions, where the developers can fulfil users' demands with visual representations. Thirdly, based on different users' intentions and contextual pressures, interactive functions allow users to customise the visual representation and storyline.

Do you think FINVID is easy to be used for developing IDV?	It depends. It is considerable easy to adapt the principles and process of FINVID to the visual representation and interaction design part. Once the requirements have been documented, following FINVID, the visual representation and interactive functions can be matched with them. However, it has been very challenging in the case study to acquire the users' demands, since it involves several rounds of discussion and demonstration. Also, if the developer is not familiar with using the norm specification, they might not be able categories requirements to different parts, such as semantic meaning, user intentions, and contextual pressure.
Do you think five steps of FINVID is easy to understand and follow?	I think it is easy to understand, since it can be a generic process of designing an artefact. However, when it comes to the practice, it involves several consulting sessions and workshop to demonstrate the IDV artefacts with users and collect feedback from them. Especially for the Development Cycle and Step 4 and Step 5, the quality of outcome might rely on communication and analysis capacities of the development team.
Do you think FINVID can be generally applicable in different IDV development scenarios?	Yes. I think it can be regarded as a generic solution for developing IDV in scenario of market analysis. The same process can be applied to monitor trends of market environment as well as analyse the customers survey results.
Do you think the results and artefacts produced with the aid of FINVID can be replicable in other scenarios?	Yes. I think for the method, it can be reused in other cases. In terms of results and artefact, it depends on the following two key factors. Firstly, the knowledge and experience of consultant play a very important role for collecting the requirements, since at the beginning the users were not very sure about what they exactly look for and their requirements were changing during when they were trying the IDV artefacts. Secondly, the role of experts is also key in the final stage for help user structure their storyline, conclusions and new hypotheses. It requires not only the participation of development team but also the expert with professional knowledge, such as marketing analysis, business analysis and visual design and communication. In summary, although for FINVID as method it can be reused, insufficient capacities and knowledge of the project team might undermine the quality of results and artefact.
Do you think FINVID offers an innovative way to help construct an integrated solution for developing IDV? It integrates the methods of requirement engineering, procedure of visualisation development, and mechanisms of knowledge management.	Yes. I think FINVID is an overall innovative solution for IDV development. It connects the different part of visualisation development methods and techniques into an integrated view. Based on my experience, I have seen those methods in different places, but lack of an integrated view. FINVID firstly tells the methods of acquiring and documenting users' requirement. Especially the usage of norm specification, it helps identify different components and categories of requirements. Instead of always reading a long paragraph of requirement description, the formula-like norm is considerably easy to read and understand with its original description as reference. Then FINVID connects requirements to different visual representation and interactive function. Especially during the discussion with users, the development team can clearly justify the reasons of designing a specific visual representation and interaction (e.g. what intention does it seek to fulfil; what context should it be used). Finally, other than focusing on the techniques and mechanisms of IDV development, FINVID also emphasises the involvement of consulting. When developing IDV under FINVID, it requires consultant with sound business analysis knowledge and communication skills, since sometime the users was very struggle to express the demands in a structured way. Also, they also find difficult to interpret the results shown in the IDV. Therefore, FINVID (in the step 4 and 6) pinpoint of contributions of consultants and experts.
Do you think that the iterative nature of FINVID is a creative	Yes. Although iterative nature of abduction reasoning approach seems a common approach that most people might have already adapted when

approach to fulfil users' demands during the process of IDV development?	analysing data and designing artefact, FINVID uses a structured way to describe as a part of IDV development method. Iterative nature can enable users continuously update their requirements during the IDV development process, which can help IDV artefact better fulfil users' demand. FINVID includes five specific steps and detailed description of development cycle. Therefore, it can ease the implementation of IDV development.