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# Large-scale Visualisations in Support of Strategic Decisions

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**Abstract.** Digitalisation of organisational processes requires decision makers to evaluate information generated by newly-adopted digital technology. Making business decisions that involve digital modelling and the impact of visualising model-derived alternatives on strategic decision-making has not been explored by neither management nor visualisation literature. Current visualisation research lacks studies evidently connecting data visualisation to decision-making in the corporate environment. This research addresses this gap by investigating information visualisation requirements when digital alternatives are shown in the context of multi-perspective distributed decision-making, where multiple stakeholders will have different information needs as well as evaluative and decision-making tasks. This study contributes to the visualisation research agenda by focusing on explicit visualisation support to management decision-making in organisations by: 1) exploring information and visualisation requirements for cross-functional stakeholders, 2) developing information visualisation principles to support collaborative distributed decision-making, 3) exploring visualisations as evolvable boundary objects.

## Introduction

In R&D-driven organisations where large volumes of experimental data is produced, teams need new approaches to presenting algorithmic predictions to decision makers. The use of predictive modelling for product innovation allows efficiency gains, shortening the product development cycle and much more (Becker et al., 2005; Bohanec et al., 2017; Fichman et al., 2014). However, trust and confidence to make a decision, as strategic as launching a product to market, based on a digital recommendation are not unconditional. Machine-generated recommendations need to be reviewed and analysed by people to narrow down best candidate selection and consequently make relevant business decisions. Management research studying strategic decision-making concerns information search, evaluation and selection of alternatives as steps of a decision-making process traditionally defined by Cyert and March (1992), Harrison (1975). However, a decision-making process that involves practice of generating and visualising predicted alternatives has not been explored in management studies. On the other hand, visualisation research is short of studies exploring decision makers' activities to claim that visualisations connect to and support business decisions. This PhD research addresses this gap and investigates three aspects of decision-making with digital modelling and visualisations.

First, it explores information visualisation requirements for strategic decision-making by different stakeholders. Visualisations are used for making sense of data and information. Their purpose is to represent, select, transform and present data in a visual form to facilitate its exploration and understanding (Keim et al., 2008; Kirk, 2016, p.19; Lurie and Mason, 2007). Only recently, visualisation research started to explore various aspects of human cognition and decision-making as a task (Dimara et al, 2018; Luo, 2019; Padilla et al., 2018; Patterson et al., 2014; Perdana et al., 2019), but visualisation is not explicitly linked to decision-making (Dimara et al., 2022).

Second, this research focuses on developing information visualisation principles to support distributed decision-making. Collaborative strategic decision-making with digital modelling takes place around shared cognitive and digital artefacts that must provide information relevant to stakeholders with different managerial expertise. The task of deciding about what action to take on digital recommendations becomes a shared decision-making space for these stakeholders. In this space, interactions occur between people; people and a digital modelling interface; and, people and digital output. Thus, decisions result from a process that propagates representations of information about computer-generated recommendations and the business context through the cognitive system of human actors and digital tools.

The third contribution stems from the previous two and explores a view of visualisations as evolvable boundary objects that can provide meaningful visual renderings of digital predictions to distributed stakeholders.

# Research question

Looking into a field problem as an opportunity to create knowledge, the following Research Question is posed:

RQ: How can data visualisations help distributed decision makers understand multi-dimensional data and results of predictive modelling?

Research objectives:

(1) Explore new digital information requirements of senior decision-makers needed for strategic decisions
(2) Convert these requirements to a feasible approach of visualising the results of predictive modelling
(3) Develop an approach through implementing a set of prototype visualisations and validating it with decision makers in a series of iterative improvements.

I draw on the concept of Boundary Objects to develop principles of visualisation designs for distributed digital decision-making. Boundary objects can be tangible artefacts or abstract concepts which represent different meanings depending on the perspective, motivations, and requirements of different stakeholders (Star and Griesemer, 1989). Their 'within-practice' and 'across-practice' positioning can be shared throughout different contexts (Carlile, 2002; Start, 1989). Their 'shared surface referents' provide a common platform for collaboration that allows stakeholders maintain their distinctive perspectives, positions and practices (Winter and Butler, 2011). Their 'interpretive flexibility' (Pawlowski and Robey, 2004; Start, 1989) and malleability make them impactful when boundary objects enable 'complex networks of actors to cooperate at a nexus of multiple social worlds' (Winter and Butler, 2011). Exploring multidimensional visualisations for decision-making as boundary objects is expected to provide observations and insights to feed into principles of creating visualisations that help stakeholders understand results of predictive modelling. So that, designed for different levels of decision-making, such visualisations can be articulated for different collaborative within- and cross-functional business communities, and at the same time, should be able to reflect their priorities, practices, and support confidence. For example, visualising the results of digital modelling for a sustainable product alternative should be flexible and evolvable for managers from R&D, supply chain and marketing to make pertinent decisions.

# Methodological approach

## Single Case Study

An FMCG manufacturing company is used as a case study to explore principles of creating visualisations for collaborative digital decision-making. Defined as 'an in-depth inquiry into a specific and complex phenomenon set within its real-world context' (Yin, 2013), a single case study allows close examination of facts, evidence and information within a specific setting (Yin, 1994, p.40). This research is an exploratory case study from a product development setting.

## Action Design Research (ADR)

This PhD research follows the action design research method used for generating actionable knowledge through creating and testing IT artefacts that emerge from 'design, use and ongoing refinement in context' (Sein et al., 2011). Since strategic decisions are made in the context of business situations, the ADR method is well-suited to merge theory, practice and research interventions in the proposed setting. Following the method, each version of an artifact will be evaluated by drawing on relationships between interative assessments of the artifact (visualisation as a boundary object) and theoretical knowledge, as shown in Figure 1.

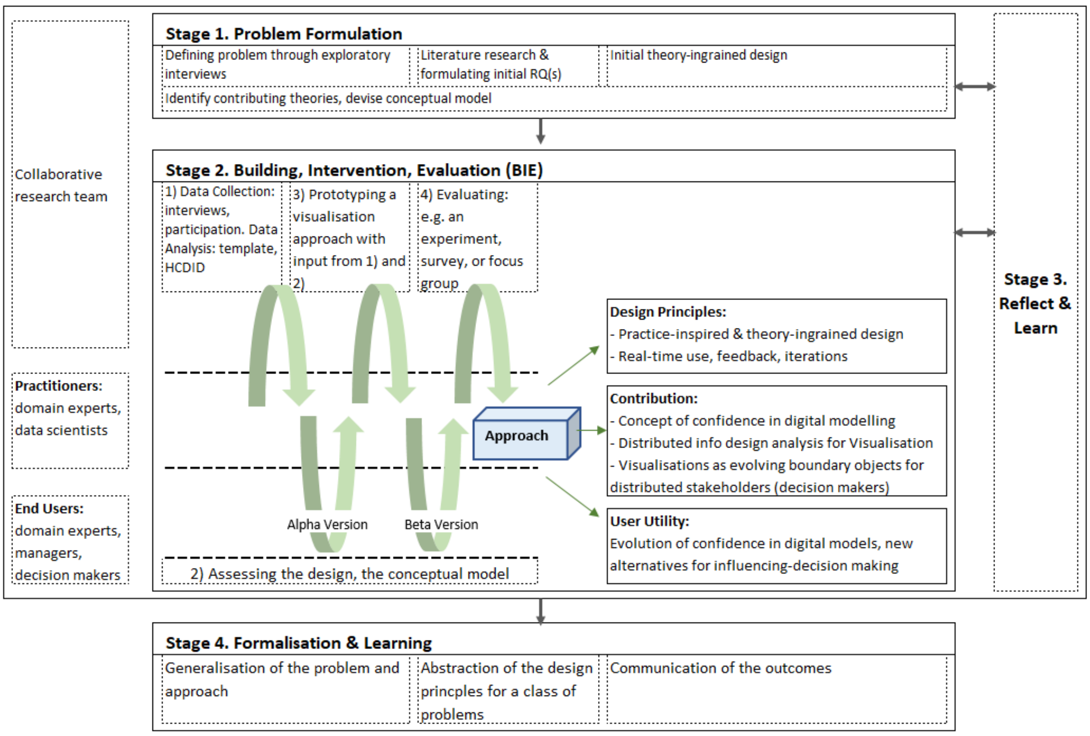



Figure 1. ADR Organisation-Dominant BIE, adapted from Sein et al. (2011)

### Data Collection and Analysis

The use of semi-structured and unstructured interviews was selected as a primary data collection technique because it is best suitable for an intensive qualitative study (Healey & Rawlinson, 1993). The objectives of the interviews were to 1) investigate the decision-making process with digital modelling, and 2) capture requirements for information visualisation.

Collected data was organised using the human-centred distributed information design (HCDID) methodology. The HCDID is based on the theory of Distributed Cognition (Hutchins, 1995; Zhang and Norman, 1994) and offers an approach requiring multiple levels of analysis (Zhang et al., 2002). According to the HCDID, the unit of analysis is a system composed of human and artificial agents, and their relations distributed across time and space (Zhang et al., 2002). The distributed information analysis was used to determine which aspects of digital recommendations are relevant to and what data and information visualisation are required by distributed stakeholders. This kind of analysis provides a framework for studying different perspectives of distributed interactions taking place in the digital decision-making process, and cognitive issues involved in designing information representations for a complex distributed, collaborative environment, such as new product development.

## Work and findings to date

### Interviews and Distributed Information Analysis

The research started with semi-structured interviews within the case study company. Interviewing has allowed engaging with key practitioners and users across relevant departments and teams. Eleven interviews have been conducted with a) data scientists, informaticians and modelers responsible for building predictive modeling capabilities; b) R&D project team leaders and managers directly involved in product development; and c) global decision makers responsible for the strategic direction and implementation.

I used the HCDID methodology to carry out a distributed information and visualisation requirements analysis. Four key components of the analysis are: user, function, task and representation.

#### Users

Three types of users have been identified. First, a digital team of data scientists, statisticians, informaticians and modelers. Second, direct users of the digital modelling output, who are technical domain experts with different levels of experience. These users are expected to understand what predictive models represent, but they do not know how a digital modeling algorithm generates recommendations. To use a digital modelling workflow, direct users need to be upskilled and trained. The third group comprises of non-technical domain expert (e.g. business managers), who are unlikely to be direct users of the workflow, however they form a cross-functional decision-making team who decide on actions with regards to the implementation of digital predictions. A relevant design of the visual representation of the modelling output is essential for different types of users.

Distributed functional analysis

The digital team is responsible for building predictive model capabilities, testing the models, workflow building and working with domain experts on using digital tools in their daily activities. The primary function of the digital modelling workflow is to support technical domain experts in R&D to develop products. The users will provide input into the digital modelling interface as a benchmark against which it will run the models and recommend best possible options given multiple input parameters and modelling objectives. Computer-generated recommendations need to be interpreted and validated by the experts. Then, successful candidate(s) can be presented to the cross-functional decision-making team as a product recommendation for manufacture and launch in the marketplace. This final recommendation must provide information relevant to all stakeholders with different functional expertise.

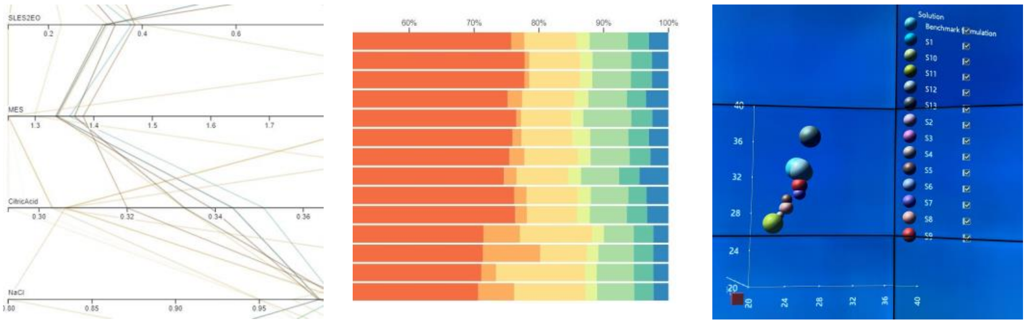
Distributed task

As the digital modelling workflow is designed to generate product recommendations, each prediction has technical, raw material, performance and cost information per recommended alternative. For the distributed task analysis, I explored decision-making tasks of each stakeholder group involved in the process.

Distributed representational analysis

Representational analysis for the 'digital team' group is out of scope in this research. For technical domain experts: each recommendation needs to display product physical properties, attributes, parity/significant differences from the standard, and several business metrics. This group of stakeholders should be able to evaluate alternatives with a high degree of data granularity on a technical level. For the cross-functional stakeholder groups, data visualisations need to answer their key questions of concern at business/managerial level, rather than details of each predicted recommendation at technical levels.

The above analysis has been used to prototype initial visualisation designs based on data output from the digital modelling workflow. The design prototypes are intended to function as a Boundary Object representing a meaning to different stakeholder groups. The prototyping has been done using the D3-Data Driven Documents approach (Bostock et al., 2011) to create interactive 2D visualisations and the DXR package (Sicat et al., 2019) for Unity to create immersive 3D visualisations, see Figure 2.




a) b) c)

Figure 2. Interactive visualisations built with D3.js (a, b) and DXR for CAVE2 (c).

# Next steps

Next steps will involve experimentation and validation involving users (decision makers):

(1) Validating prototypes with stakeholders through iterations
(2) Testing the utility of the boundary object for the users
(3) Developing research findings into a research paper

# Expected contributions

This PhD study contributes to visualisation research by focusing on information visualisation support for decision-making, an area that has received little explicit awareness in the visualisation research publications (Dimara et al., 2021; Dwyer et al., 2018). My contribution to knowledge is three-fold: 1) exploring information and visualisation requirements of distributed stakeholders, 2) developing information visualisation principles to support distributed decision-making in a corporate innovation environment, 3) exploring visualisations as evolvable boundary objects.

# References

Becker, M. C., Salvatore, P., and Zirpoli, F. (2005): ‘The impact of virtual simulation tools on problem-solving and new product development organization’, *Research Policy*, vol. 34, no. 9, July 2005, pp.1305–1321.

Dwyer, T., Marriott, K., Isenberg, T., Klein, K., Riche, N., Schreiber, F., Stuerzlinger, W. and Thomas, B.H. (2018): 'Immersive Analytics: An Introduction' in K. Marriott, F. Schreiber, T. Dwyer, K. Klein, N. Henry Riche, T. Itoh, W. Stuerzlinger, B.H. Thomas (eds.) *Immersive Analytics*, pp.221-257, Springer Nature Switzerland AG.

Bohanec, M., Robnik-Šikonja, M. and Borštnar, M. (2017): 'Decision-making framework with double-loop learning through interpretable black-box machine learning models', *Industrial Management & Data Systems*, vol. 117, no. 7, August 2017, pp.1389-1406.

Bostock, M., Ogievetsky, V., and Heer, J. (2012): 'D³ Data-Driven Documents', *IEEE Transactions on Visualization and Computer Graphics*, vol.17, no. 12, October 2011, pp.2301-2309.

Carlile, P.R., (2002): 'A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development', *Organization Science*, vol. 13, no. 4, pp.442-455.

Cyert, R. and March, J. (1992): *A Behavioral Theory of the Firm*. 2nd edn. Blackwell Publishers, Cambridge.

Dimara, E., Bezerianos, A. and Dragicevic, P. (2018): 'Conceptual and Methodological Issues in Evaluating Multidimensional Visualizations for Decision Support', *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, no. 1, January 2018, pp. 749-758.

Dimara, E., Zhang, H., Tory, M. and Franconeri, S. (2021): 'The Unmet Data Visualization Needs of Decision Makers within Organizations', in *IEEE Transactions on Visualization and Computer Graphics*, April 2021 (early access), doi: 10.1109/TVCG.2021.3074023.

Dimara, E. and Stasko, J. (2022): 'A Critical Reflection on Visualization Research: Where Do Decision Making Tasks Hide?', *IEEE Transactions on Visualization and Computer Graphics*, vol. 28, no. 1, January 2022, ppEkr.1128-1138.

Fichman, R., Dos Santos, B., Zheng, Z. (2014): 'Digital innovation as a fundamental and powerful concept in the information systems curriculum', *MIS Quarterly*, vol. 38, no. 2, June 2014, pp.329-354.

Harrison, F. (1975): *The Managerial Decision-Making Process,* Houghton Mifflin Company, Boston.

Healey, M. and Rawlinson, M. (1993): 'Interviewing business owners and managers: a review of methods and techniques', *Geoforum*, vol. 24, no. 3, pp.339-355, via Elsevier ScienceDirect Journals [Online]. Available at: doi: 10.1016/0016-7185(93)90026-E

Hutchins, E. (1995): 'How a cockpit remembers its speeds', *Cognitive Science*, vol. 19, pp.265-288.

Keim, D., Andrienko, G., Fekete, J. D., Görg, C., Kohlhammer, J., and Melançon, G. (2008): 'Visual analytics: Definition, process, and challenges' in A. Kerren, J. Stasko, J.D. Fekete, C. North (eds.) *Human-Centered Issues and Perspectives,* Springer Berlin Heidelberg, pp. 154-175.

Kirk, A. (2016): *Data Visualisation: A handbook for Data-Driven Design,* Sage Publications Ltd., London.

Luo, W. H. (2019): 'User choice of interactive data visualization format: The effects of cognitive style and spatial ability', *Decision Support Systems,* July 2019, vol. 122, pp.1-11.

Lurie, N. and Mason, C. (2007): 'Visual Representation: Implications for Decision Making', *Journal of Marketing*, vol. 71, no. 1, January 2007, pp. 160-177.

Patterson, R., Blaha, L., Grinstein, G., Liggett, K., Kaveney, D., Sheldon, K., Havig, P., and Moore, J. (2014): 'A human cognition framework for information visualization', *Computers & Graphics*, vol. 42, April 2014, pp.42–58.

Pawlowski, S.D., and Robey, D. (2004): 'Bridging User Organizations: Knowledge Brokering and the Work of Information Technology Professionals', *MIS Quarterly*, vol. 28, no. 4, December 2004, pp. 645-672.

Perdana, A., Robb, A., Rohde, F. (2019): ‘Interactive Data and Information Visualization: Unpacking its Characteristics and Influencing Aspects on Decision-making’, *Pacific Asia Journal of the Association of Information Systems*, vol. 11, no.4, December 2019, pp.75-104.

Sein, M., Henfridsson, O., Purao, S., Rossi, M. and Lindgren, R. (2011): ‘Action Design Research’, *MIS Quarterly*, vol. 35, no. 1, pp. 37-56.

Sicat, R., Li, J., Choi, JX., Cordeil, M, Jeong, W-K., Bach, B. and Pfister, H. (2019): 'DXR: A Toolkit for Building Immersive Data Visualizations', *IEEE Transactions on Visualization and Computer Graphics*, vol. 25, no. 1, January 2019, pp.715-725.

Star, L.S. (1989): ‘The Structure of Ill-structured Solutions: Heterogeneous Problem-solving, Boundary Objects and Distributed Artificial Intelligence’, in M. Huhns and L. Gasser (eds.): *Distributed Artificial Intelligence*, vol. 2, Morgan Kaufman, San Mateo, CA, 1989, pp.37-54.

Star L.S. and Griesemer, J.R. (1989): ‘Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39’, *Social Studies of Science*, vol. 19, no. 3, August 1989, pp.387-420.

Yin, R. K. (1994): *Case study research: Design and methods*, 2nd edn., Newbury Park, CA: Sage

Yin, R. K. (2013): ‘Validity and generalization in future case study evaluations’, *Evaluation*, vol. 19, no. 3, pp. 321-332.

Zhang, J. and Norman, D. (1994): ‘Representations in Distributed Cognitive Tasks’, *Cognitive Science*, vol. 18, pp.87-122.

Zhang, J., Patel, V., Johnson, K. and Smith, J. (2002): ‘Designing Human-Centered Distributed Information Systems’, *IEEE Intelligent Systems*, vol. 17, September 2002, pp.42-47.

Winter, S., and Butler, B. (2011): ‘Creating bigger problems: grand challenges as boundary objects and the legitimacy of the information systems field’, *Journal of Information Technology*, vol. 26, April 2011, pp.99-108.