

Visualisations and cognition in behavioural operations management: (de-)biased decision-making

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Abstract

This paper deals with the role of visualisations on cognitive biases in behavioural operations management. Using a scoping and mapping study both realms of information visualisation and behavioural operations management (BOM) are linked by the shared mechanisms of perception and cognition. By doing so, possible visual means to influence certain cognitive biases in BOM are identify. To further investigate the application of visualisations in the organisational and individual decision-making processes in BOM contexts in practice, a case study research framework and protocol, including measurement instruments like semi-structured interviews and observations, are derived and presented for further usage.

Keywords: Information Visualisation (InfoVis), Cognitive Bias Mitigation, Behavioural Decision-Making

Introduction: visualisations to mitigate or enhance cognitive biases

Visualisations' purpose is to facilitate analysts' perception and cognitive processing of the information inherent in specific datasets. Therefore, visualisations are also used in operations management (OM) as a matter of course to ease the presentation of information, to solve tasks, and to make decisions concerning, e.g., production-related aspects.

Nevertheless, although information systems (IS), decision support systems (DSS) or technology in general are already investigated by the behavioural operations management (BOM) community, the role of visualisations in indeterministic problem settings like inventory decisions or forecasting is rarely addressed.

However, despite visualisations undoubted capability to overcome or at least mitigate cognitive limitations of ours, misleading visual representations of data in production and operations management (P&OM) at the same time may as well result in costly outcomes of decisions (Bendoly, 2016).

Therefore, from a theoretical as well as managerial point of view, it is of interest and importance to know the underlying cognitive and perceptual mechanisms in decision-making that may favour the one or the other outcome.

This leads us to pose the following research questions (RQs) that we are addressing in this paper:

- (1) What are the available possibilities and how might they be derived to influence behavioural biases in P&OM by means of visualisations – according to the literature?
- (2) How should a case research be designed to investigate how P&OM practitioners and organizations are implementing and using visualisations in BOM contexts, and to what extent they are aware of their capabilities to mitigate and enhance cognitive biases in decision-making?

Therefore, by the means of a scoping and mapping study, we are first investigating common behavioural biases that are observed in OM as well as its driving mechanisms, and are linking them with visual means that might be able to influence (de-)biased behaviour and decision-making in respective P&OM contexts.

Subsequently, we conceptualise a case study research to explore our theoretical assumptions on the relation between visualisations and decision-making in BOM based upon the prior findings concerning RQ1.

In the following sections we are introducing the theoretical backgrounds on visualisations and cognition in general and in (production) management in specific, on which we are building our further investigations. Then, we present the applied methods to find answers to our research questions, i.e., a scoping and mapping study as well as the development of a case study research. The resulting literature mapping and case research concept are then explained in the subsequent section, before their implications are finally discussed and the paper is concluded.

Background: relations between visualisations, cognition and management

Information visualisation (InfoVis) as a discipline is on the one hand closely related to information and data science as well as human-computer interaction (HCI) and statistics. On the other hand, it is also linked to cognitive and perceptual psychology (Keim et al., 2008). Thus, there exist commonalities with behavioural economics (BE) and BOM (Figure 1), where human non-hyper-rational behaviour and decision-making, influenced – among others – by cognitive biases, are investigated (Fahimnia et al., 2019).

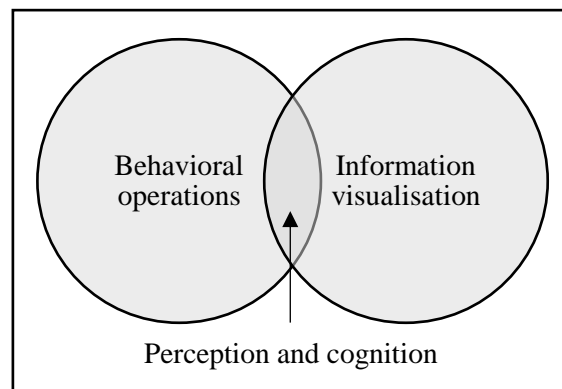


Figure 1 – Common backgrounds of behavioral operations and information visualisation

So far, the role of visualisations in management has been investigated both from an organizational as well as an operational point of view. From an organizational viewpoint,

e.g., Meyer et al. (2013) are investigating the state of the art of visuals in organization science and are identifying thus five different research approaches how visuals are commonly understood and analysed. Meyer et al. (2013) praise the variety of different research approaches and perspectives in this field so far. But they conclude also, that only few streams were substantially pursued further. Therefore, the authors argue to investigate more in depth individual visual semiotics as well as the act of sense-making and decisions on a micro level.

From an operational viewpoint, the most prominent examples are probably from lean management, where concepts like the visual control for management on the shop floor have already been addressed (Bateman et al., 2016). But also, e.g., Greif (1991) describes benefits of a visual communication on the shop floor. But, while these approaches are aiming mainly at directing the attention of the workers on certain aspects of the production and are informing them about deviations from the plan, DSS research considering visualisations provides further support to take more complex decisions with eventually more uncertain outcomes (e.g., van Capelleveen et al., 2021).

Both perspectives are of interest to our research, as operations management decisions on the individual level are both influenced by organization as well as they are impacting the organizations performance in total.

Methods: scoping study to derive case research protocol

First, we are conducting a literature review at the intersection of an overview, scoping and mapping study (Grant and Booth, 2009) and second, we are deriving from the first a protocol for a case study research, following Voss et al. (2002), investigating the individual decision-making processes of operations managers using visualisations as well as their role in and for the organizations.

Scoping and mapping study

Compared to a systematic review, the goal of our study is to broadly scope the literature concerning (1) cognitive biases in BOM and (2) visualisations considering cognitive and perceptual aspects in general to gain an overview and link both realms of research rather than analysing in detail a narrow range of literature. This means also, that no specific search or quality criteria are necessarily applied. Nevertheless, the search protocol follows a similar structure as a systematic literature review (SLR):

1. Identifying the research question,
2. identifying relevant studies,
3. study selection,
4. charting the data,
5. collating, summarising and reporting the results (Arksey and O'Malley, 2005).

Therefore, as RQ1 has been already defined above, the relevant studies were identified by starting from seminar, text- and handbooks as well as reviews and meta-analyses from the disciplines of BOM, OM, P&OM, lean management, supply chain management (SCM), organisation management, IS, DSS, business process modelling (BPM), behavioural economics (BE), InfoVis and cognitive psychology. Using forward and backward searches from this literature further articles were considered that were relevant to answer RQ1.

Concerning the management, BE and psychological as well as IS and decision science (DS) literature, papers were considered eligible that were dealing with cognitive (excluding social) biases (like, e.g., BOM literature) and/or with visualisations in specific. On the other hand, the focus in assessing relevant InfoVis literature was on the

fundamental description of specific uses and effects of individual visuals and visual elements on perceptual and cognitive processes. In identifying this literature, conference papers played a greater role, using also a list of Kosara (2013).

After reaching a theoretical saturation, when only few further insights were generated by considerably higher efforts, the search for further literature was stopped. Finally, the resulting body of literature was used to link the found impacts of different visuals on perception and cognition with the identified cognitive biases and mechanisms behind non-rational behaviour in OM settings. Figure 2 shows the different focuses of the assessed research as well as the respective amount of identified papers. The results are then also described, interpreted and concluded in the end.

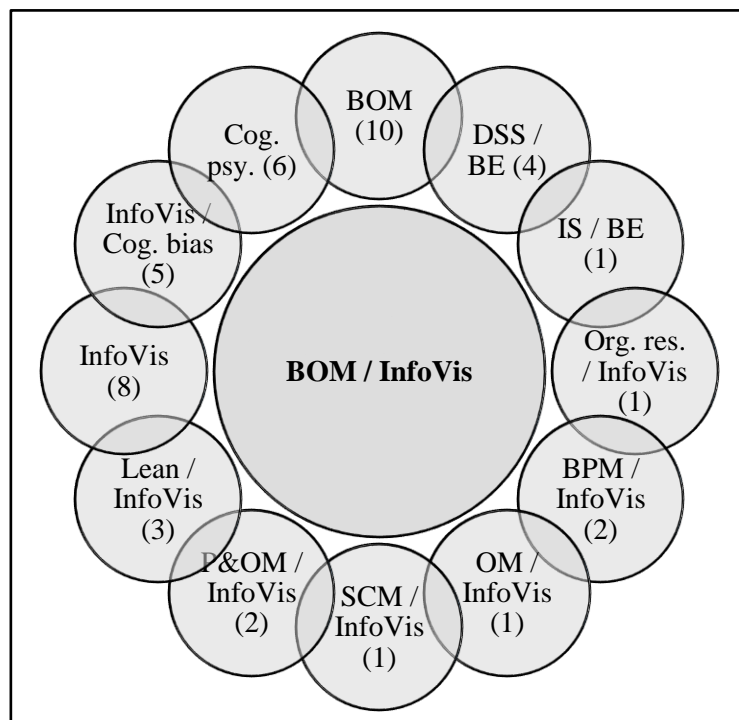


Figure 2 – Research disciplines and focuses of the assessed literature (and amount of papers)

Case study research protocol

According to the well-established approach of Voss et al. (2002) to conduct case research in operations management, we are building upon the (theoretical) findings of the scoping and mapping study to investigate more in detail in the field specific organizational framework conditions as well as individual decision-making processes using visualisations in OM contexts. While Voss et al. (2015) distinguish seven steps for conducting case research, we are treating here only the first four steps of the design phase:

1. Rationale for case research,
2. developing the research framework,
3. case selection and
4. developing the research protocol.

Thus, our rationale to apply case study research is, that it suits very well for our purposes (RQ2), as it is able to especially investigate why, what and how the nature and complexity of decision-making processes using visualisations in OM contexts is characterised (Voss et al., 2002).

Although we are basing our case study research on the existent literature and are already proposing relationships between variables of BOM and InfoVis, there is still

uncertainty about the definition of the constructs and thus, we are mainly following a theory-building approach of the case research (Voss et al., 2002; Voss et al., 2015).

Nevertheless, the prior grounding of our case study research in the existent literature (RQ1) from various perspectives strengthens the internal validity of our case research approach (Voss et al., 2015). Furthermore, we are triangulating the data gathered (construct validity) and ensure the external validity as well as reliability of the case research within the research protocol as developed and described in the next section.

Results

Literature mapping and linking

Figure 3 first maps the investigated BOM contexts with commonly reported reasons for cognitive biases in these contexts, based on the assessed BOM literature like Bendoly et al. (2010) and Fahimnia et al. (2019). Thus, in many contexts, individual risk preferences and bounded rationality (both in six contexts) are reported, followed by cognitive reflection, and judgement bias (both 3). The least frequently reported causes of cognitive biases in these contexts are the endowment effect and cognitive appraisal (both 1).

Based on the findings from the InfoVis-related literature and own judgement, the most common and feasible possibilities of designing individual visual elements or whole visualizations are also presented in Figure 3 and linked to causes of cognitive biases that they might influence. Noteworthy, the categories of visual means are not distinct. I.e., visual means (e.g., colour) to increase the salience of certain information can be used to create a new reference point at the same time. These two categories represent also the most reasonable visual possibilities to mitigate the most of the identified causes of cognitive biases (both 4). E.g., similar to textual framing, visual framing could change risk preferences by highlighting either positive or negative aspects and/or moderate effects due to certain degrees of cognitive reflection (system 1/system 2 thinking).

Visualizing uncertainty and/or risk (3) is reported in an extra category as it is using even more visual elements and a more or less own body of literature dealing with it. Therefore, to visualize uncertainty and risk, visual elements and encodings are, e.g., combined to depict whole distributions of probabilities of values to realize or certain ranges.

Visual bias feedback (3) as, e.g., described by Wall et al. (2017) draws especially from interactive visualizations and derived performance (or bias) indicators based on the user's interaction patterns (observed via log data or eye tracking) with the data. Where there might be possible biases—e.g., due to omitting certain data points for inspection—, the risk of being prone to a certain bias might be depicted visually. Similarly, Kaul et al. (2022) have tested the visualisation of counterfactuals to improve decision-making.

Representations with graphs and networks (2), i.e., using nodes and edges, are common in operations research, but seem less effective to mitigate the most frequent reported mechanisms underlying cognitive biases in BOM. Nevertheless, reasonable applications of such visuals might be for the less frequently reported biases, so far, e.g., due to mental accounting or the endowment effect. In these cases, the depiction of the origin, connection, and pathway of elements might clarify visually the affiliation of certain information or data.

Finally, other visual means that could be applied to mitigate certain cognitive biases could be different interaction techniques, signs or symbols (that might already have commonly understandable or certain cultural or community-based encodings), or even pictures of real elements.

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		Cognitive bias due to (derived from mentions in assessed BOM literature)										
		Risk preference	Bounded rationality	Cognitive reflection	Judgment bias	Reference dependency	Overconfidence	Mental accounting	Cognitive dissonance	Regret	Endowment effect	Cognitive appraisal
BOM context (according to assessed BOM literature)	Contracting	•										
	Inventory management (news vendor) and bullwhip effect	•	•	•	•	•	•	•				
	Procurement and auctions	•										
	Service operations		•	•								
	Revenue management	•			•							
	Forecasting	•			•	•	•					
	Quality management		•						•			
	Capacity management		•							•		
	New product development	•	•				•	•		•	•	
	Production management	•		•		•						
Process improvement		•						•			•	
Visual mean (based on assessed InfoVis literature and own academic judgement)	Visual salience	•		•		•				•		
	Visual reference point	•		•		•				•		
	Visualizing uncertainty/risk	•		•			•					
	Visual bias feedback		•		•		•					
	Graphs (networks)							•			•	
	Others (e.g., interaction, symbols, pictures, ...)		•	•				•		•		•

Figure 3 – Mapping literature concerning cognitive biases in OM and related visual means

Case study research framework

Based on our literature study and prior findings, we now first conceptualize the research framework underlying our case research, as suggested by Voss et al. (2002) and depicted in Figure 4. At the core of our investigations lie the individual reasoning, sense-making and decision-making processes of the operations managers while using visualisation tools. Together with the task requirements, the individual preconditions of the managers and the use of visualisation tools are supposed to influence the strain, the managers are experiencing. On the organisational level, framework conditions and results of the individual decisions can be observed.

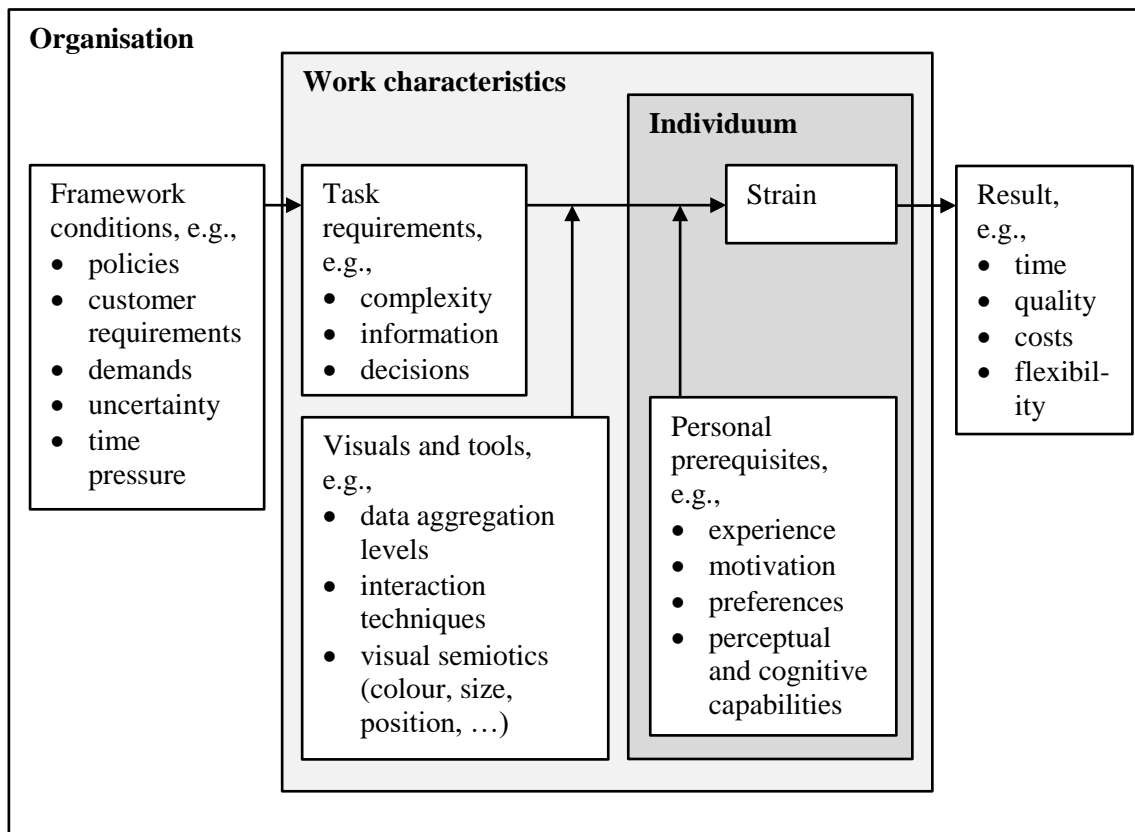


Figure 4 – Research framework depicting constructs, categories and relationships (adapted from Bornewasser et al., 2018)

Derived from this conceptualization of relationships between the constructs of interest (and in relation to our RQ2), we are interested in answering the following general questions with our case research:

- How are organisations and individual decision-makers in P&OM implementing and using visualisations?
- How are visualisations influencing the decision-making processes in P&OM contexts and why?

Case selection

Referring to our literature mapping observed behavioural biases in P&OM with possible visuals influencing the cognitive mechanisms behind them (Figure 3), we can further narrow down our research design to a specific P&OM domain. Guiding our selection, e.g., by the chances to assess any kind of behavioural biases, according to our map, we should expect several different biases in inventory management. At the same time, the underlying mechanisms causing these biases have several possible visuals to influence them, according to our map. By focusing on a specific context – inventory management – we are expecting more in-depth inferences. However, to still strengthen the generalisability of our envisioned results, we are aiming at researching several case companies and several inventory managers each. In this way, we should be able to compare inter-personal similarities and differences (within companies) as well as inter-organisational ones (between companies).

In theory-building case study research, as in our approach, Voss et al. (2002) propose to select cases that predict either similar or contrary results, but for predictable reasons.

Furthermore, according to Miles and Huberman (2008), samples consisting of representative cases, disconfirming and exceptional ones let expect the greatest pay-off.

As in our case we are not (yet) aware of representative or extraordinary cases where visualisations have been applied in P&OM practice, we see the major possibility to select similar and different cases alike by varying in the following criteria, while keeping the general context of inventory management decisions constant (sample control). With varying size, revenue and industry of the case companies, we expect to see differences in the organisational framework conditions like customer demands and management policies (Figure 4), in the task requirements (due to different intra-organisational aspects) as well as in the characteristics, variety and usage of visualisation tools. On the other hand, variations in the individual prerequisites of the managers will probably only be feasible concerning different levels of, e.g., professional experience and will be highly dependent on the respective key informants within the companies that provide access to. Other aspects like motivation or personal preferences will be less likely known by the key informants. However, an assessment of these factors beforehand with surveys bears the risk to deter people from participating due to the sensitive and very personal topic of individual work practice as well as sense- and decision-making.

Also due to this, extraordinary caution should be given to the selection, address and communication of the purpose and conduction of the research when approaching key informants to gain access to case companies. Thus, probably the most feasible way would be a convenient sample via key informants that are already positively attained with the researchers and/or research, e.g., via previous and current research projects. In a next step, the beforementioned sample characteristics may then be considered.

Research protocol

To assess the constructs and categories of interest (Figure 4), we are using different instruments. Regarding the organisational aspects and framework conditions, questions are asked in semi-structured interviews, but also publicly and otherwise accessible company information from documents are gathered.

Concerning the decision-making processes on the individual level, we are also applying semi-structured interviews (pre- and post-decision-making) but are also including personal observations using a job shadowing approach (Czarniawska, 2007).

According to Simon (1960) the human decision-making process can be divided into three stages (intelligence, design and choice), according to Witte et al. (1972) even into more or less six subsequent phases: (1) identifying the problem, (2) obtaining the necessary information, (3) producing possible solutions, (4) evaluating the solutions, (5) selecting a strategy and (6) implementing the action(s). To retrace the individual decision-making processes in our cases, we are thus also reflecting these steps in the observation sheet.

To let the participants reflect on the decisions they made, the following post-interviews should be conducted whenever possible and reasonable. To do so, we are adapting the decision probe interviews with production planners of Gasser et al. (2011) and based on Crawford et al. (1999) to our purposes.

I.e., our overall interview and observation guidelines cover the organisational framework conditions, task characteristics, applied visualisation and information systems as well as partly the personal prerequisites, strain and outcomes (Figure 4).

And finally, the used visualisation tools and the kind of data (or real data, where possible) are also used afterwards to retrace the interactions and decisions as well as

explore and assess alternative behaviour and outcomes that were not displayed or observed.

Discussion and conclusions

With our scoping and mapping study of the management and visualisation literature, including its intersections, we made a first step towards closing the gap between the BOM and InfoVis literature, based on the common cognitive links between both research domains. In this way, we were mapping at least theoretically suitable and reasonable visual means to mechanisms behind cognitive biases in P&OM to influence the observed (non-rational) behaviour of decision-makers in these contexts (Figure 3). Thus, this approach is well in line with the management research agenda concerning the specific role of visualisations on a micro-level (Meyer et al., 2013) as well as in OM in specific (Bendoly, 2016).

Furthermore, based on the identified literature, we derived the framework for a case research to be able to assess in practice the usage of visualisations and tools by companies and individual decision-makers to identify the factors that are influencing the decision-making with visualisations in P&OM practice (Figure 4). In specific, we also presented the procedure of case selection and the research protocol for a respective case research, where we assess the necessary data through triangulation by documents, interviews and observations.

Although this is still work in progress and the data still has to be collected, we think that the preliminary work of linking the domains of BOM and InfoVis (Figure 3) as well as the tentative research framework (Figure 4) can already help interested peers to start their own endeavours concerning visualisations, cognitive biases and OM. They may use the derived assumptions from the literature and our groundwork to develop their own research questions, derive hypotheses and research protocols for both qualitative and quantitative research approaches.

Nevertheless, besides their tentative status, the development of the case selection process as well as the research protocol have shown the difficulties of (a) the access to case companies due to the sensitive topic of individual decision-making processes as well as (b) the additional assessment of personal data on preferences or similar. It will thus also be necessary to find further ways to overcome these hurdles.

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