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Towards a Situation-Awareness-Driven Design of Operational Business Intelligence & Analytics Systems

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Abstract. With the swamping and timeliness of data in the organizational context, the decision maker's choice of an appropriate decision alternative in a given situation is defied. In particular, operational actors are facing the challenge to meet business-critical decisions in a short time and at high frequency. The construct of Situation Awareness (SA) has been established in cognitive psychology as a valid basis for understanding the behavior and decision making of human beings in complex and dynamic systems. SA gives decision makers the possibility to make informed, time-critical decisions and thereby improve the performance of the respective business process. This research paper leverages SA as starting point for a design science project for Operational Business Intelligence and Analytics systems and suggests a first version of design principles.

Keywords: Operational Business Intelligence & Analytics, Design Science, Situation Awareness

1 Introduction

In today's business world, information represents a major competitive factor [1]. The provision of the right information to the right person at the right time is crucial to stay ahead of competitors and is a key concern of Business Intelligence and Analytics (BI&A) [1, 2]. The concept of BI&A represents a data-centric approach using historical data to provide an organization's management with relevant information to support strategic or tactical decisions [1, 3]. Case-specific technological architecture and implementation concepts established decision support from strategic level to operational decisions which we coin Operational Business Intelligence and Analytics (OpBI&A) [2]. However, using systems realizing such OpBI&A concepts can result in serious challenges in the business world of operational decision makers (also referred to as actors). Actors at the operational level face the challenge to meet business-critical decisions in a short time at a high frequency with high volumes of data [4]. For instance, in algorithmic trading, actors have to make sell or buy decisions within 0.5 milliseconds in order to prevent information decline [5]. Furthermore, the swamping of data tends to aggravate the problem of information overload for operational decision makers [6] and requires adequate decision support by information systems

(IS) [4]. Thus, the number of time-critical decision-related situations for an actor rises constantly due to the timeliness and density of data consumption at the operational level [7]. The supply of task- or situation-specific information represents a necessary, but not a sufficient condition to solve these issue [8]. To provide actors the possibility to take an appropriate decision alternative in time-critical situations, a decision maker must achieve an adequate level of Situation Awareness (SA) of the current situation [9]. The construct of SA has been established in cognitive psychology and is considered as an essential antecedent of an individual's decisions and actions [10]. Thereby, SA describes a constantly updated state of an actor's (external and internal) knowledge of the environment in relation to a particular task [9]. Studies show that as much as 88% of human error is due to problems with SA [11]. For instance, in August 2003 inadequate SA caused the largest power blackout in North America and led to costs between $4 billion and $10 billion for the United States alone [12]. As cognitive concerns have great impact on the individual level, it seems reasonable to study adequate situational decisions from this perspective. Accordingly, we propose that OpBI&A systems are sought to anticipate the actors' SA in their design. However in the exploration of the IS research area, we could not find any artefact aiming to support decision making for operational process execution that (1) explicitly considers specific cognitive concerns, and (2) bases on a sound theoretical foundation. Only a limited amount of IS research addresses cognitive issues as important design factor. For instance, Schieder [8] labeled the area as an promising research direction, whereas Leite and Cappelli [13] complain that software engineers deport this issue to other research areas. The identified literature for designing OpBI&A systems focuses mainly on technological blueprints. This literature neither provides assistance in the design of such systems nor considers the impact of the resulting systems to the user's work environment from a cognitive perspective. Consequently, this design science research (DSR) project aims to create a SA-driven design for the class of OpBI&A systems to increase decision making performance. In order to address the practical relevance of the topic, this DSR project is conducted in cooperation with a large software vendor. The industry partner developed a software product situated at OpBI&A. In the project, we will enrich the system with SA-driven design concerns. Thus, we formulate the following overarching research question for our research:

Which design principles for operational BI&A systems support situation awareness of decision makers and increase their decision-making performance?

The remainder of the paper is as follows. First, related work and the theoretical foundations are discussed and the research method is shown. Next, the first version of the meta-requirements (MRs) and related design principles (DPs) for the software artifact, grounded by literature, are presented, before the paper is concluded.

2 Related Work

Traditionally, BI&A represents a data-centric approach which supports strategic and tactical decisions on the basis of (mainly) retrospective analysis aligned to a limited audience of managers and BI experts [1, 3]. Instead of associating data with business processes, traditional concepts, e.g., online-analytical processing, separate the data analysis and information retrieval from process execution [1]. Currently, BI is facing a paradigm shift towards providing day-to-day decision support during process execution to overcome these obstacles [1, 5]. Examples for such innovative BI approaches, technologies and architectures are described by the following concepts.

Operational BI leverages BI methods and provides analytical information in order to manage and optimize daily business operations [2]. Research highlights increased performance gains through the provision of analytical information to operational decision makers [14]. Due to the narrow time frame for the analysis on the operational level, the provision of up-to-date information is needed [14]. The support of (near) real-time decision making with minimal latency is commonly referred to as *Real-time BI* [7]. Another capability is related to settle analytical information to its process-context to support the transformation of enterprise strategies from the strategic to the operational level [1]. For instance, *Process-Centric BI* (PCBI) describes functionalities (data analysis and information provision) for decision support in connection with the execution of business processes [1]. Thus, there is a range of technically oriented proposals to design innovative BI architectures supporting operational decision support. However, it is assumed that the outlined software packages will support additional technologies in the future and that their boundaries will disappear [5]. Although these architectures focus on different content areas, they all share the common goal of exploiting, integrating and providing information from very heterogeneous sources for operational decision support, while maintaining the lowest possible time latencies [8]. This includes analytical information on the basis of historical data from traditional data warehouse systems as well as current data from process monitoring and/or from external data sources and information. The specific requirements resulting from the operational context, especially cognitive influencing factors, are considered (at most) rudimentary in the identified articles. Potentially the construct of SA could provide fruitful insights to address cognitive concerns in the OpBI&A systems design.

3 Situation Awareness

Operational decision makers in daily business are more dependent on a current, intuitively understandable description of the situation regarding the choice of decision alternatives than this is the case for the strategic level [4]. It must be ensured that the relevant information for a given situation can be perceived by the actor in the amount of incoming signals [4, 6]. Research on decision-making in highly complex and dynamic decision-related situations identified SA as dominant factor for success [10]. The construct of SA describes the state of an actor with respect to three, coherent set of levels [9]: Level 1 is described as the actor's perception of the characteristics, status and dynamics of relevant elements in a situation. Level 2 is defined as the actor's comprehension of the meaning of the objects and events for its situation. Level 3 is characterized as the actor's ability to project (near) future actions of the elements in the environment. These three levels of SA are determined by task or system factors on the one hand (e.g. human-machine interface design, actor's workload), and individual factors on the other hand (e.g. actor's capacity of attention, working memory) [9]. Consequently, SA is formed through the interaction of an actor with his environment. This interaction strongly influences subsequent decisions and actions taken by a decision maker. Thus, changes of the task/system or individual factors require an adjustment of SA [9]. However, due to this interaction, forming and maintaining SA can be a difficult process for actors [15]. Endsley and Jones [16] defines these difficulties as "SA Demons", such as data overload or complexity. Based on these considerations, Endsley [9] developed a taxonomy of errors affecting SA at each of its three levels. In order to tackle down the SA Demons [16], IS should support decision making and preparation by assisting the actor in obtaining the above mentioned three levels of SA [17]. However, despite their close connection, decisions and actions represent independent stages that pursue directly from SA [16]. In addition, actors with perfect SA could still take the wrong course of action, for reasons such as lack of training or an inability to carry out the necessary actions [9]. SA does not guarantee optimal situational decisions and actions. Rather, SA describes an important antecedent to enhance the probability to arrive at better decisions and actions [9]. To further improve our understanding of SA and the design of systems to improve operational decision making, we examine the applicability of SA in the context of OpBI&A. We expect, that our work will yield useful insights into the design of user interfaces suited for operational decision making.

4 Research Method

The research project follows a design science research (DSR) methodology process as described by Peffers et al. [18], applying the design and development-centered approach. This approach is usually taken if an already existing artifact might have not been reasoned out as a solution for the identified problem, have been leveraged to solve a different problem from a different research domain, or have been appeared as an analogical idea [18]. Currently, our industry partner provides an analytical application that does not consider cognitive concerns regarding SA. Thus, this project aims to enrich its design by incorporating DPs that specifically address SA. The application of DSR was chosen since this project should address both, developing a theory-grounded SA-oriented design for OpBI&A systems and evaluating its impact on a user's decision making. As shown in the previous sections, the existing body of knowledge lacks a theory-grounded SA-oriented design [19] for the entire class of OpBI&A systems. From a practioner's point of view, the operational decision maker's SA represents an important issue to meet business-critical decisions in short time and at high frequency in order to prevent expensive mistakes. Our industry partner is highly conscious of the issues relating to decision maker's SA and its customers serve as real business cases.

5 Situation-Awareness-Driven Design

Following the conceptual foundation and principles suggested for SA (e.g. by [9] [16]), we present a first version of SA-driven DPs for an OpBI&A system which enforces the needed information to an operational decision maker without inconsiderable cognitive effort. Thereby, the identified DPs build on all coherent sets of SA levels: **perception** (level 1), **understanding** (level 2) and **projection** (level 3). A SA-oriented design supporting all levels of SA has shown to increase the probability to develop effective and efficient systems, which in turn foster decision making and performance [12]. In order to achieve a high SA level, the corresponding SA Demons need to be addressed [16]. Endsley [9] developed a taxonomy of SA errors to address these Demons. We suggest MRs based on the SA Demons and the taxonomy to inform our DPs.

Level 1. From the cognitive science perspective, OpBI&A systems should support the actor's perception of all relevant data and information of the system environment, its elements and their relationships within the relevant socio-technical system. As a first step in providing such perception, data needs to be made available to an actor (**MR1**) [20]. However, the continuously increasing heterogeneity of data elements (e.g. historical data from data warehouses or real time data in form of sensor feeds or RFID scanner units) perceived by operational decision makers represents a major challenge to achieve MR1. Accordingly, the design of OpBI&A systems should address these concerns when presenting information to an actor. In other cases, data is available, but data detection and discrimination is problematic [20]. This phenomenon is often associated with the SA Demon "Misplaced Salience" [9]. Salience is defined as the compellingness of specific shapes of information which largely depend on its physical characteristics [12]. Certain signal characteristics are more affected by an actor's perceptual system than others [15]. The color red, movement and larger noise represent examples which are more likely to attract an actor's attention [16]. Salient properties represent important features to denote actors to important cues in a system and to promote SA. However, if such properties are utilized too often or inappropriately, it may lead to actors' confusion and errors since the actor would not be able to identify the critical information [16]. Such issues would draw an actor's attention unintentionally to less certain information and make it more relevant to the actor than it actually is. Accordingly, OpBI&A systems should leverage salience without over-emphasizing to support an actor's ability to detect and discriminate data (**MR2**). Our third MR facilitates an actor's ability to monitor and observe data by tackling the SA Demon "Attention Tunneling" [16]. Actors have to switch their attention between different sources of information to maintain a high level of SA [12]. However, decision makers often lock their attention on only certain aspects of the environment that they attempt to process, while neglecting unintentionally their scanning behavior [16]. As a result, decision makers will achieve a high SA in the area of their concentration, while becoming outdated in areas they are not watching [15]. Thus, dynamically switching attention between different areas of interest remains a challenge for actors and needs to be considered explicitly in the design of OpBI&A systems (**MR3**). Another SA Demon is called "Requisite Memory Trap". In many situations, actors leverage short-term (working) memory to store, put together and organize units of information [15]. Essentially, the working memory represents rather a restricted repository to store information [12]. Common SA failures arise from not sufficient space or the natural information dissolution over time in the working memory. Given abstract information (e.g. a phone number or sign) such dissolution may occur in 20-30s [16]. Accordingly, the design of OpBI&A systems should not heavily depend on the actor's short-term memory when presenting information to an actor (**MR4**). The volume and frequency at which data is changed, generates the need for quick information absorption which quickly exceed the sensory and cognitive abilities of an actor to provide this need [12]. This SA Demon is called "Data Overload". In a given state, an actor can only intake and process information to a certain degree at a time [15]. When the auditory or visual information exceeds the cognitive threshold of an actor, the decision makers SA will generate gaps or become outdated [16]. Often such issues arise in areas where systems fail to provide a fair degree of accuracy of the relevant cues in data sampling [9]. Thus, the system has to prevent such data overload (**MR5**). Another SA Demon refers to "Workload, anxiety, fatigue, and other stressors" (WAFOS) affecting the actor's ability to intake information as well [12]. Such stressors can affect SA significantly by reducing the already restricted short-term memory capacities of an actor to collect information efficiently [16]. This effect increases the probability to succumb to attentional tunneling and make a decision without considering all available information. Particularly, stress environments with low latencies and high information volumes are influenced negatively by WAFOS [15]. The efficient absorption of information by an actor should be considered in the OpBI&A design (**MR6**). We summarize the MRs by formulating our first DP:

DP1: *OpBI&A systems should support an actor's perception of a current situation.*

Level 2. The dynamics of operational decision-making situations usually require a timely integration and provision of necessary knowledge for the decision making [2]. Only if this goal is met, actors can achieve an understanding of the current situation [9]. To provide a high comprehension of perceived data, MR7 addresses the SA Demon "Errant Mental Models". Large knowledge units in the long-term memory are referred to as mental models which help actors to comprehend how something work [16]. However, errant mental models might cause errors during the execution of a task [12]. Such errors are typically insidious since an actor might not recognize that the utilized model is incorrect [15]. For instance, decision makers tend to use even far-fetched explanations to fit conflicting information to their incorrect mental model [16]. Consequently, the design of OpBI&A systems has to support situations where decision makers form and maintain correct mental models (**MR7**). In addition, the reliance on default values in mental models has to be reduced as well [9]. Default values describe general expectations of an actor about how certain parts of the system work [20]. For instance, in the absence of real-time data, decision makers often leverage these defaults for decision making and actions [20]. However, in new situations the default values might be inappropriate or outdated which could cause significant SA errors [9]. Consequently, OpBI&A systems should provide an actor with appropriate data (e.g. in real or right time) to overcome the reliance on an actor's default values (**MR8**). The SA Demon "Complexity" represents a further problem for developing an adequate level of comprehension [12]. Many systems incorporate complexity by introducing too many features [16]. This feature escalation makes it difficult for actors to create and maintain a correct mental model of how such systems work [15]. Thus, keeping complexity to a minimum should be addressed in the OpBI&A system design (**MR9**). Another SA Demon is the "Out-of-the-Loop Syndrome" referring to a system's automation degree. The higher the degree of automation and the state of elements the automation is alleged to control, the higher the probability that an actor will form a low SA level [12]. An actor's state of being out-of-the-loop represents no problem as long as automation is performing well [16]. In case of automation failure, however, actors which are out-of-the-loop are often not able to identify problems, understand the information displayed and anticipate in time [15]. Thus, an appropriate level of automation in the design of an OpBI&A system is needed (**MR10**). We summarize the four MRs by the following DP:

DP2: *OpBI&A systems should enable an actor's understanding of a current situation.*

Level 3. From a cognitive perspective, OpBI&A systems also need to support the projections of probable future states of an environment. Actors may fully understand the current situation, without being able to anticipate the current future [20]. Mental projection represents a challenging task [9]. Explanations are miscellaneous ranging from poor mental model development to overreliance on a decision maker's mental simulation abilities [20]. Thus, OpBI&A systems need to facilitate the formation of a correct mental model (**MR7**) as well as the prevention of overreliance on an actor's mental simulation abilities (**M11**). Thereby, the design of OpBI&A needs to support both, lower SA levels in order to identify possible outbreaks or data patterns and higher levels of SA to examine the future effect of information. For instance, the application of predictive analytics could be leveraged to build and assess models in order to identify patterns and to make empirical predictions about business situations [21]. Such BI practice includes tools and techniques of statistical process control, data mining and simulation and offers support for the analysis of the impact of various alternatives of action to an actor. Accordingly, the operational decision maker could anticipate immediately the perceived trends without being highly dependent on its mental simulation abilities. The required information would be derived, for instance, by predefined regression analysis, which are generated by including various environmental factors and using trend lines for visualization. However, the complexity of these tools is a major obstacle for their effective use [8]. Thus, complexity issues need to be addressed accordingly (**MR9**). Based on the above mentioned MRs we formulate the following DP:

DP3: *OpBI&A systems should assist an actor's abilities to predict future situations.*

6 Conclusion

Applying the DSR approach, this paper contributes to BI&A research. The construct of SA is used as a starting point for the development of DPs for OpBI&A systems. SA represents a well-established construct in psychology for understanding and explaining the interconnectivity of external knowledge components in dynamic, time-sensitive and decision-related situations in on-going, cognitive processes [10]. The conceptualization of SA shows an analogy to OpBI&A since extraction, consolidation and delivery of information for time-critical situations describes a core responsibility of OpBI&A. This paper discusses issues in SA including the actor's perception, understanding, prediction capabilities and the related SA Demons. We derive eleven MRs informing three DPs for OpBI&A systems based on these foundations. As next steps we conduct interviews with BI experts and customers of the industry partner to refine the DPs and implement a prototype by incorporating the redefined DPs into the exiting OpBI&A product.

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