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Situational Management and Digital Situational Awareness Systems in Infrastructure Construction: Managerial Perspectives on Relevance, Challenges, and Adoption

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Abstract: Currently, digital situational awareness systems are popular in complex infrastructure construction projects. These systems monitor and assess environmental events, progress, resource availability, risks, and other project decision-making variables to support decision-making. However, little is known about how infrastructure construction (IC) professionals who utilize situational awareness systems perceive how they support or hinder situational management. The purpose of this exploratory research is to study, in depth, the relevance, challenges, and adoption of situational management in IC projects using digital systems. The data were collected via semistructured interviews with 21 IC managers and situational awareness management experts from 11 companies involved in railway projects. The main findings indicate that problem-solving improved with situational management in general, especially with digital situational awareness systems. Seizing the possibilities for transparency that accompany digital situational awareness systems helped in discussing emerging problems and making project choices. Expectations about the realism of such expectations were easier to align with historical event data. On the other hand, the informants reported difficulty in motivating contractors to collect situational data in digital form, possibly because of a lack of understanding about the purpose of data collection, the manual nature of data collection, the perceived excessiveness of data collection, or the manual transfer of collected data into digital form. For these reasons, the informants reported limited faith in these systems. A perceived drawback of situational management, whether supported by digital situational awareness systems or not, was its lack of applicability to the realities of a construction site. Systems were designed for project management needs but not tailored to the needs of construction projects. The interviewees' statements indicate that maintaining situational awareness requires active interaction and constant checking of the provided information, even requiring pressure on the contractors providing the information. This study highlights the need for practical human approaches to effectively use digital situational awareness technologies and situational management in IC.

Keywords: infrastructure project management; situational management; situational awareness

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1. Introduction

With the increasing use of digital situational awareness (SA) systems in complex infrastructure construction (IC) projects, there is a growing understanding of how IC professionals who use SA systems perceive situational management (SM). In the current study, digital SA-based systems refer to systems that aim to continuously and automatically monitor and assess environmental events and track progress, resource availability, risks, and other variables used in a project's decision-making. SA is an individual approach guided by principles such as situational leadership (i.e., a guiding approach) and a systemic perspective on how to approach

complex phenomena (i.e., a system approach). SA has long been recognized as crucial for human decision-making [1], especially in IC management, which often relies on rapidly aging situational data and fragmented and manually collected pieces of information. Although SA is a person's dynamic understanding of "what is going on" [1], SM is an adaptive, reactive management approach based on manual or digital activity monitoring [2,3]. It entails adapting management styles and techniques to different dynamic situations: SM requires analyzing, making decisions, and exerting control that is tailored to each specific situation to optimize the organization's response [1–4]. In infrastructure projects (ICs), the situations in and around subway systems, urban railways, and other wide-ranging projects are typically complex [5] and often geographically scattered, particularly when connected to a digital sensing system [6]. SM has been found to be an effective management and coordination technique, although the focus of IC has suffered from an overemphasis on technology.

In recent years, digital SA systems for SM purposes have been developed and tested in IC and other construction sectors. In the current study, digital SA-based systems refer to those systems that aim to continuously and automatically monitor and assess environmental events and track progress, resource availability, risks, and other variables used in a project's decision-making [1]. SMs are adaptive, reactive management methods that are based on manual or digital activity monitoring [2,3]. Many of these digital systems have primarily concentrated on ensuring safety and monitoring the whereabouts of heavy machinery and workers [7–9]. An example of a typical sensing application for management is SA systems, which have been implemented in large and complex systems such as maritime surveillance and operations [10].

Although digital SA systems have become increasingly common in IC management, past research has neglected the perceptions of IC professionals who use SA for SM. These perceptions include, but are not limited to, the challenges and benefits of digital SA systems, the relevance of SA in the work of IC professionals, and the adoption of SA systems and SM. For instance, Sacks et al. [11] discussed the potential usefulness of SA systems within and outside digital SA systems but failed to consider the SM component. Indeed, in their study, Sacks et al. [11] proposed potential managerial gains that could be attained; however, they deferred the exploration of this knowledge to future research. Akinci [12], Ghimire et al. [13], and Martinez et al. [14] proposed valuable conceptual frameworks for effectively managing construction projects through the use of SA systems. However, they failed to offer specific examples of how SA system adoption has been carried out in projects and the practical experience of managing these systems and SMs. Hence, the objective of the current study is to investigate the viewpoints of experts on IC projects using SA systems and SM and provide empirical evidence from individuals' experiences to support the current conceptual bodies of knowledge. Specifically, we present the following research questions:

(1) Which aspects of SA systems and SM are relevant for IC management professionals when utilizing SA systems?
(2) What are the perceived benefits and challenges of SM among IC management professionals?
(3) How do management professionals influence the adoption of SM in IC projects?

The present study utilizes prior SA research and SM research conducted among professionals in the fields of health care, law enforcement, manufacturing, and traffic control to compare the use of SM as a management technique in these established research domains with its application in IC. The present paper presents the findings of 21 interviews with IC professionals from 11 different companies. The interviews focused on professionals' perceptions of SM while utilizing SA systems in their daily work in IC projects. The insights of these IC professionals are relevant for scholars and practitioners because they provide useful and current first-hand knowledge on the utilization of digital SA systems and the implementation of SM in IC projects. These perceptions, which are relevant to the individual IC professional, can be utilized not only for gathering data but also for recognizing and explaining the different systemic challenges and benefits of digitally enhanced SA [15]. The findings of the current study are transferrable to other areas of construction, even though the current emphasis has been on IC.

2. Literature Review

2.1. Situational Management Concept

Dickson et al. [16] highlighted the importance of informal leadership in SM, Johnstone and Cooke [17] stressed the importance of a systematic process in SM, Lee et al. [18] presented the relevance of SM in managing abnormal situations, and Fatkieva and Korytov [19] and Oloufa et al. [7] showcased the practicality of SM and SA in autonomous vehicle management. Like researchers, practitioners might also interpret the concept of SM differently. Some have considered it the style of management, while others have taken it to refer to the situational leadership concept [20], in which managers adapt their organizations to the situation [21]. In the latter view, SM is expected to adapt and adjust to the situation and produce a leadership style that will generate a willingness to act in each situation [4].

As a management method, SM is linked to management models for different dynamic and complex systems (such as traffic or emergencies) using different algorithms and information systems [18]. The systemic perspective is based on the view that organizations are complex systems and that only after analyzing a situation is it possible to choose the appropriate solutions [22]. The systemic perspective often involves steps similar to SA concepts, such as situation identification and assessment, selection and decision-making, and monitoring [23,24]. Both perspectives on SM (style or system) are relevant to the current study, which explores how people perceive SM.

2.2. Situational Management Research in Fields Other Than the Construction Industry

Healthcare is one of the main areas of research in the field of SM. In healthcare, the emphasis is on client (i.e., patient) behavior. Here, behavior refers to situations that are constantly evolving and dynamic in healthcare, such as encounters with threatening clients and critical treatment emergencies [3,25,26]. Within treatment situations, studies have shown that SM may also be applied to patients, with the key objective of steering the situation in the desired direction [27]. In this context, SM can be viewed as the reactive management of a situation according to learned patterns.

Other healthcare research on SM has focused on managing people in crisis situations, where flexibility tends to be more necessary [28,29]. The most recent studies on this topic refer to SM in the context of frontline management during the COVID-19 pandemic [16,29,30]. Healthcare researchers do not refer to SM as a proactive tool; rather, they emphasize its immediate reactive nature [3].

Healthcare research on SM has indicated that situational management does not need to prioritize digitalization and information technology. SM in healthcare appears to focus more strongly on individuals, teams, and human behavior than on technology. Healthcare SM emphasizes reactive action to the acute situation at hand and the safe guidance of such situations to a desired state or conclusion [27]. In healthcare, SM is aligned with Endsley's [23] SA concept, which was originally developed for making quick and reactive decisions and resolving the necessary immediate situations in military aviation operations.

Whether within or outside of healthcare, organizational management fails to emphasize the significance of digitalization and information technology in SM. Although the healthcare field seems to emphasize reactive SM rather than proactive management, this distinction is not necessary [31]. In organizational research, SM is often considered among the management styles that managers should use in certain situations [21].

Busse and Wirsing [32] argued that the classic management styles are authoritarian, democratic, and laissez-faire. Authoritarian leadership focuses on obedience and a strict hierarchy, democratic leadership values employee ideas while maintaining managerial oversight, and laissez-faire leadership trusts workers' autonomy with minimal managerial intervention [32]. According to Rubin [33], the SM style is a mixture of all these classic leadership styles, meaning that people may choose the style depending on the situation.

Another characteristic field of study in SM research is law enforcement [17]. In law enforcement, much like in healthcare, SM primarily focuses on behavior, specifically in the context of effectively managing rapidly evolving, challenging, and hazardous situations [3,17].

Much research in this area has focused specifically on the management of prison violence situations. Various methodologies have been developed, such as promoting risk interventions by SM [34], which is a systematic assessment process for situational risk in prisons and hospitals [17]. Because both healthcare and prison care involve an essential element of supervision (either of patients or prisoners), research on law enforcement has specifically identified the role of supervision and its effects on individuals and the environment, as well as the response of individuals to supervision [35,36].

Manufacturing and production are perhaps the most recent and significant research fields in SM. For manufacturing and production, the main research focus has been management culture [37–39], especially the management of abnormal production situations [18,40,41]. According to Littunen and Virtanen [37] and Littunen and Tohmo [38], SM management culture is typically characterized by independence and reactive market-driven behavior. In Engelhardt-Nowitzki's [39] study, the adaptability and improvement of SM culture are highlighted, showing the potential negative effects on staff motivation and fatigue.

SM research in the transport sector has concentrated on utilizing digital and information technology as tools. Researchers in the transport sector have examined SM in relation to SA in traffic control systems and the advancement of autonomous vehicles [19,24,42]. Although much research on traffic has focused on the development of algorithms for SM, researchers have also explored people's trust in the ability of systems to perform automated SM and have also highlighted the challenges of relying on technology [43,44].

A synthesis of the above focus areas of SM research includes reactivity, activity monitoring (manual or automatic), control of the situation, and the situational and adaptable style of managers. The clear challenge for SM is its reactive nature and associated improvisation, which are inevitable because of the changing situations that can arise. Despite its strengths, SM is not without limitations. One significant drawback is the tendency to overlook the fact that it is impossible to attain an entirely objective and honest understanding of a situation. This is because the "truth" becomes subjective and influenced by the same situational factors as effective management [21]. Therefore, it is inevitable that situational "truth" also quickly becomes obsolete because the situation is constantly changing. The ever-changing nature of situational reality poses a specific difficulty in IC, where SA is of the utmost importance.

2.3. Situational Management and Situational Awareness in Infrastructure Construction

In the construction industry, the limited research on SM has mainly focused on the management culture of construction companies [45–49] and the use of digital SA systems [9]. Management culture has been studied in terms of the directness or indirectness of communication, as well as in terms of functional objectives based on task prioritization, a decentralized and temporary organizational structure in projects, an emphasis on teamwork skills and conflict resolution skills, and adaptability to the business environment and to changing situations [45–47]. The digital aspect of SA has mostly emphasized occupational safety [50] and the verification of the whereabouts of machinery, equipment, and workers [9], rather than focusing on SA as a management system.

Sacks et al. [11] stressed that, in the construction context, SA information communicated through continuous monitoring and data analytics can be used to deduce existing conditions and evaluate future design and planning results in projects; they anticipated that integrating monitoring technologies and software agents into management systems would enhance informed decision-making by providing a comprehensive picture of the situation [11]. Similarly, the framework developed by Ghimire et al. [13] aimed to comprehensively incorporate different project situational variables (such as weather, performance, and activities) into a digital SA system. This integration should then facilitate the formation of SA, which can assist project managers in expediting the decision-making process. Their premise was that this would facilitate and motivate users of SA systems to deliberately contemplate the condition of the project and respond more analytically to challenging or unforeseen situations. Therefore, construction sector researchers and practitioners have also been investigating the concept of SA and SM, which involves adopting a flexible

and adaptive approach to managing building and infrastructure projects. This approach considers the distinct characteristics of each situation.

Previous research on IC has suggested that the significance of digital SA systems as technological systems and SA as conceptual models is likely to increase, while the value of SM as a management concept is closely tied to the utilization of SA systems [13]. Multiple researchers have emphasized the significance of SA as a crucial factor in assisting human decision-making when there are competing project information pieces in management work [11,14,51]. Despite the implementation of SA concepts and the growing interest in SM in the IC sector, there has been limited research on experts' viewpoints regarding SM in complex IC projects. Therefore, research on SA systems in the IC industry has experienced significant growth [50]. Nevertheless, the perspectives of IC professionals in the sector have been overshadowed by this technological viewpoint. Working in this context, the current study provides an exploratory and novel perspective by presenting the human perceptions of 21 IC professionals using SA in their SM approaches.

3. Methods

There is currently limited knowledge about the views of IC professionals who use SA. The objective of the present empirical and exploratory study was to investigate the perspective of SM, the significance of SA, the difficulties involved, and the implementation of SA in IC projects through the use of digital SA systems. Thus, to obtain qualitative information, the primary approach utilized for the current study was interviewing. Interviewing is particularly suitable for examining people's experiences of managing because handling the topic and gathering information require tact and diplomacy [52]. Conducting interviews with a limited number of professionals is an effective approach to gathering data, particularly when these individual professionals possess relevant and specialized knowledge on the subject and are representative of individuals from the wider population [53]. The use of semistructured interviews in the current study enabled us to collect knowledge and abundant data from a group of people on an under-researched topic of SA and SM in IC.

We collected research data by interviewing 21 people from 11 different construction companies who had experience using SM in projects. All these projects and interviewees were from Finland. The interviewees were chosen by purposive sampling, as described by Robinson [54]. Initially, we utilized publicly available data to identify major infrastructure projects that indicated the use of SA and SM in their projects. Subsequently, we contacted the project management teams to confirm the actual implementation of SA and SM and to ascertain the willingness of possible interviewees to participate in our study. Then, we presented our research plan to the company representatives and asked them to propose potential interviewees, whom we later approached with an interview request. The interviewees participated voluntarily. Every respondent we selected was provided with an individual agreement regarding data consent and the anonymization of their data.

The research team worked in Finland, and all interviews were conducted in Finnish, which allowed for face-to-face interviews. All the interviewees worked on urban railway projects. These projects, which are located in built environments and communities, are complex systems and, therefore, are appropriate for the use of SM. The interviewees were either project managers or experts in the SA system. During the interviews, the respondents worked on five different rail projects at different stages. Table 1 provides background information on the companies and projects in which the interviewees worked.

Six interviewees were from company A, two of whom worked in project management and four of whom were SA system experts. All the interviewees from companies B and C worked in project management (three from company B and four from company C). For companies D through K, only one person per company was interviewed, seven of whom worked in project management and one as an SA system expert. The interviewees were employed by companies that were either clients, consultants, or construction companies in these projects.

Table 1. Background information on the companies and projects of the interviewees.

Company	Company Type	Project Type	Project Budget (M€)	Project Phase	Company Revenue (M€) *	No. of Employees in the Company *	No. of Interviewees in the Project
A	Consulting company	Subway line	1200	Commissioning	1900	20,000	6
B	Limited liability project company owned by municipalities	Subway line	1200	Commissioning	22,520	19	3
C	Construction company	Light rail line	350	Construction	3400	5500	4
D	Consulting company	Railway line	70	Design	0.9	5	1
E	Transport infrastructure agency	Railway line	70	Design	1600 **	400	1
F	Consulting company	Light rail line	350	Construction	140	2000	1
G	Consulting company	Light rail line	350	Construction	1800	17,500	1
H	Construction company	Tramway line	200	Construction	430	600	1
I	Consulting company	Subway line	1200	Commissioning	0.250	2	1
J	Consulting company	Tramway line	200	Construction	200	19,000	1
K	Consulting company	Tramway line	200	Construction	1	12	1

* In 2022 or latest confirmed revenue ** Administrative budget.

For these interviews, we used interview notes. We recorded all the interviews. The recorded texts were transcribed via an external transcription service facilitated by the university. We analyzed the research data using thematic analysis, which is a qualitative research method for identifying and distinguishing issues pertinent to a certain research problem [55]. The variation in the content of the interviews created different themes. In the current study, we sought to answer our main research questions. We employed a method that involved the integration of thematization and typification [56]. This was achieved by applying the inductive categorization approach established by two main researchers, who were also responsible for conducting the interviews.

The main theme of the interviews was how people perceive SM. This theme was supported by the probing questions we asked as the interviews progressed. These probing questions were based on our research questions and included questions such as how respondents and others used SM to manage themselves and/or their subordinates, how their jobs changed during the use of SM, how the organization changed during the use of SM, how they started using SM, how they influenced the use of SM, any criticism or positive opinions associated with SM, and what they would change about SM. The probing questions were tailored to each respondent, incorporating supplementary questions suitable for the specific circumstances and the acquired information. These questions were exclusively employed throughout the interview after the respondents had exhausted their discussion points or had deviated from the main topic [54]. In addition, the interviewees were asked to share practical examples of situations and discussions related to SM.

The interview data were transcribed and then translated from Finnish to English. The transcribed data were then coded and processed using Atlas.ti software (ATLAS.ti Scientific Software Development GmbH, Berlin, Germany). During the coding process, all phrases in the interviews in which the interviewees said anything that referred to their or others' experiences with SM were indexed [57]. The use of thematic analysis and systematic coding allowed us to shift between the themes created by the researchers and the original expressions of the interviews. Thus, we could examine the conclusions drawn from the interviews without losing the original expressions.

The identification of expressions was performed by sorting the coded and themed expressions into subsets. In this context, "expressions" refer to sentences used by the interviewees with which they formed a view of SM or described some of their experiences related to SM. A coded and themed quote might contain part of a sentence or one or more sentences. In addition to themes, we also analyzed and synthesized any outliers, that is,

individual expressions of one person that were not raised by any other interviewees [58]. Outlier analysis can provide clues that either support or undermine thematization [59].

The study's validity and reliability were evaluated using three methods: (1) providing a comprehensive explanation and documentation of the context behind the findings, (2) analyzing outliers and alternative explanations, and (3) connecting the findings to the literature [60]. To mitigate interviewer bias, our research team consistently involved two interviewers (the primary author and the secondary author) in the interview process, with only two exceptions. The data analysis results were evaluated collaboratively with all members of the research team.

4. Findings

4.1. The Relevance of Situational Management for Infrastructure Construction Managers

Based on our analysis of the interview data, certain themes seemed relevant for SM and were consistently mentioned in multiple responses. The results demonstrate the necessity of current and pertinent SA information for the effective SM of IC projects, which can be utilized for making informed decisions. Below are a few quotes highlighting the relevance of SM in IC.

> *We [project management team] hold a meeting once a month or so to look at those figures [of the SA system] and discuss what they signify for our decision-making.*—Quote 2.16.1, a design manager from company J.

> *The first [SA system's] view must address two questions. Do we have a problem, and where is the problem?*—Quote 2.2:19, a project director from company A.

> *I'm constantly dealing with the [SA system] numbers and know what's behind them, but they [the project management team] have. . .limited time to look at it and make a decision. . .putting an awful lot of data on them will not result in a decision.*—Quote 2.18.11, an SA system expert from company A.

> *. . .it depends on what you're leading and how effectively the [SA system] reflects reality in terms of how relevant the [SA information] is. In addition, the [SA system] represents our forecasts. It would be fantastic if there was some deeper predictive analysis here. . .once we have that data. . .*—Quote 2.1.1, an SA system expert from company K.

The relevance of SM lies in the analysis and interpretation of the data from the SA system and how this information influences decision-making. Another significant application of SM appears to be the identification, localization, and resolution of issues, as mentioned by multiple participants during the interviews. However, the experts specifically pointed out that management has a limited amount of time to analyze a vast quantity of SA data. They emphasized the relevance of having appropriate information for decision-making purposes. Many respondents, including managers and experts, believed that forecasting and anticipating could enhance decision-making processes. However, they also noted a lack of improvement in their SA systems related to this aspect.

4.2. Perceived Benefits and Challenges of Situational Awareness and Situational Management in Infrastructure Construction

Table 2 summarizes the expressions interpreted by the interviewees as benefits and challenges.

Two prominent themes on SM were evident in the comments, which were well-received by many participants. Both themes revolved around problem-solving: discussions on the urgent situation and enhanced transparency in the project. The observed problems pertaining to decision-making include a deficiency in the implementation of previously made decisions, as evidenced by the lack of follow-up in the decision log. A number of participants expressed their approval of utilizing SA for decision-making, anomaly detection, workflow optimization, and predictive analysis. Two respondents expressed appreciation for the utilization of the SA system for project reporting, while three respondents voiced dissatisfaction with the SA system's lack of use for operational management of the site.

Additionally, two respondents criticized the monitoring conducted through the SA system, perceiving it as a manifestation of mistrust.

Table 2. Benefits and challenges of the SA system and SM in infrastructure construction.

Theme (B = benefit; C = challenge)	**Respondents' Role Companies**										
SA system benefits and challenges		A	B	C	D	E	F	G	H	I	J	K
(B) Current situation of IC project and event history viewable	6 Managers, 4 Experts	x		x			x		x	x		x
(B) SA system supports discussion and problem-solving in IC projects	3 Managers		x	x				x				
(B) One can influence SA system development in IC project	2 Managers										x	x
(B) SA system is useful for reporting in IC project	2 Managers		x				x					
(C) SA data collection was laborious and expensive	5 Manager, 2 Experts	x	x	x								
(C) SA data are only collected for IC management needs	4 Managers		x	x		x						
(C) SA system is not used for IC site operations	3 Experts	x		x								x
(C) Manual SA data collection work error-prone	3 Managers			x			x					x
(C) More visual SA content from the IC construction site needed	2 Managers		x						x			
(C) SA data collected beyond necessities	1 Manager, 2 Experts	x										
(C) Monitoring via SA system perceived as a lack of trust	1 Manager, 1 Expert	x								x		
SM benefits and challenges		x	x							x	x	
(B) SM enables deviation intervention in IC project	3 Managers, 1 Expert	x	x							x	x	
(B) SM facilitates decision-making and problem-solving in IC project	4 Managers, 2 Experts	x	x		x		x			x		x
(B) Regular review of the situation together by the IC management team	2 Managers, 1 Expert	x					x	x				
(C) Purpose of SA information unclear to SA system users	3 Managers, 2 Experts	x	x	x		x						
(C) SA information not used by responsible IC professionals	3 Managers	x	x						x			
(C) SA information considered unreliable by the IC professionals	3 Managers			x			x			x		
(C) IC professionals are ignoring decision logs of the SA system	2 Managers		x						x			
(C) The contractor has no incentive to provide correct SA data	1 Managers		x									

Note: The numbers 1 . . . n in the "Respondents' role" column refer to the number of respondents.

The positive SM views also encompassed the frequent collaborative evaluation of the problem, as emphasized by three distinct responders from three separate companies. The primary challenge was the lack of comprehension of the purpose of the information, as reported by five respondents representing five distinct companies. In this context, two respondents also expressed criticism of the contractors' motivations.

The most beneficial component was the ability to see the present situation and past occurrences of various events in the SA system. Both interviewees had favorable views regarding the visual aesthetics of the system. The primary obstacles encountered with the system were the arduous process of data gathering and the lack of confidence in

the reliability of the data among individuals. Additionally, manual data collection was criticized by four separate interviewees. Three interviewees expressed the opinion that an excessive amount of data was gathered compared with what was actually necessary, while four interviewees said that the data were collected solely to meet the demands of management. Two respondents expressed skepticism about the reliability of the data gathered by the contractors. Two participants from separate organizations expressed their approval of the opportunity to contribute to the advancement of the SA system, while one participant expressed contentment with the amount of working time that was made available as a result of the SA system.

4.3. Individuals' Contributions to Situational Management Implementation

The interviews also emphasized many crucial features of individuals' contributions to the implementation of SM. Initially, the respondents highlighted the customization of SA tools and techniques:

> *. . .the sites look like their master. . .if you understand, maybe you may demand that "hey, I'd like to have [SA] tools and [SA system] views like this on my own site or for my own administration."*—Quote 2.1.10, an SA system expert from company K.

The interviewees acknowledged that varying projects and scenarios may necessitate customized approaches, which is a fundamental aspect of SM. Many comments suggest that the management techniques of IC projects related to SM require flexibility and customization.

Furthermore, a majority of the interviewees played a crucial role in both the creation and preservation of SM, with a special focus on the SA system. The specialists were responsible for gathering SA data and verifying its accuracy. Additionally, they ensured that the contractors, who were the primary sources of these data for the SA systems, consistently provided the required information. Regarding this matter, the feedback had a significant personal impact on certain individuals, as seen in the following quotes:

> *In practice, I simply feed in [SA] information from others. However, I also have to act as a mediator, determining whether this [SA data] is correct or reasonable. Alternatively, if you provide a [schedule] date but another date is provided, there will be two dates for the same [schedule] event. Additionally, as a reminder [I remind], "Please complete this by this day and this date."*—Quote 2.10.3, an SA system expert from company A.

> *. . .I have to push them [the contractors] to identify those future [schedule] milestones. . .and it makes me feel like the SM model is not in place for them, but it is a disconnect if they have not identified those kinds of essential things. . .they have not reviewed the [SA] information that has been provided to the situation center on construction site. The fact that we [SA system professionals] must push them [contractors] and develop a mechanism to ensure that they study and analyze that [SA data]. That is when it appears to be they do not care about the [SA] data. . .*—Quote 2.11.21, a project director from company A.

> *It is difficult to determine where management ends and SA begins, but I visit the site and speak with my subordinates, have one-on-one interactions, and then, there's the management team. . .I. . .spend two days a week. . .on that SA [and]. . ..what. . .the actual project situation is.*—Quote 2.15.30, a production manager from company C.

The statements made by the interviewees indicate that IC professionals play a crucial role in handling the intricacies of the SA process for SM. They not only receive information passively, but they also actively seek, send, and check information on the SA system to ensure its accuracy and usefulness. The interaction between IC project management and contractors is evident, as indicated by the responses. This interaction involves the exchange of information as well as the examination and validation of SA data. This indicates a shared effort to maintain the integrity and usefulness of the SM and SA systems. However, several interviewees (both managers and SA system experts) also expressed frustration and distrust toward contractor performance and motivation regarding SA and SM.

4.4. Outlier Analysis

We also analyzed outliers in the current study [59], as well as individual expressions that no other interviewees mentioned. These outliers may be summarized under a few key themes. First, some respondents felt that decision-making processes were slow and fragmented, often based on subjective rather than informed factors, and that too much time was spent on risk management. Second, the respondents noted problems associated with SA sessions, such as too much analysis, frequent follow-up periods, and overly busy sessions that exhausted the participants. Third, the respondents noted problems with project management, such as unclear objectives, overreliance on traditional planning models, and a lack of trust in the system.

Other problems that emerged through individual expressions included the use of unnecessary goals, confrontations between contractors, and an intergenerational gap in the use of SA. Several individual expressions also painted a picture of technical problems, which the interviewees attributed to the lack of an SA standard, flawed reporting models, and the placement of data on a network drive rather than in the cloud.

Overall, these individual expressions were linked to expectations of clarity in SM and decision-making processes and the improved reliability of technical solutions. The need to improve the efficiency and usefulness of SA sessions also emerged from individual expressions.

4.5. Summary of Findings

The interviews provided insights into the relevance, challenges, and adoption of SM for professionals utilizing SA systems in IC projects. First, the beneficial aspects were related to improved problem-solving. According to the interviewees, using SM and SA systems helped them to regularly discuss and solve project problems and make decisions. Respondents also saw transparency in decision-making as having improved problem-solving, for example, in relation to different types of deviations and work organization and forecasting. In addition to foresight, being able to view the history of events (e.g., event logs), in addition to the current perspective, emerged as a beneficial aspect of the responses.

The main challenge of SM was the limited motivation of contractors to collect data in their clients' SA systems. In particular, the respondents criticized manual data collection in digital systems as being cumbersome, expensive, and inaccurate. The interviews also revealed a lack of confidence in the collected data. The responses also gave the impression that not all parties involved in the IC project necessarily understood the purpose for which the data were being collected.

SM did not yet extend to the construction site. The respondents perceived it mainly as a method of project management. The provided responses can be considered a form of introspection as the participants themselves held key roles in the project and were directly or partly responsible for the development of the SA systems, with the on-site component being inadequately represented.

5. Discussion

IC management professionals perceived the use of SM as improving the project team's problem-solving abilities and allowing open and regular discussions before decisions were made. However, as a management method, SM did not seem to meet the needs of the site staff but rather met the needs of the project management team. The specific nature of problem-solving in the construction industry, compared with other sectors such as manufacturing and production, is that problems arise unpredictably on-site and must be addressed immediately [61]. The problems solved at a construction site are highly context-specific, change over time, and must be solved with peers and colleagues [62]. In this respect, IC is analogous to healthcare and transportation from the perspective of SM. Considering that the construction site is also a substantial source of these problems in IC projects [63], the absence of site-level SA and SM prompts numerous considerations. The problem with the use of SA systems seems to be that these systems are developed to adapt and manage dynamic situations in context-driven situations, but they are mainly used

for project management purposes rather than to address immediate, unpredictable, and highly context-specific problems on IC sites. In the current development of SA systems in IC, based on our findings, there seems to be a traditional mismatch between site needs and project management needs [64,65]. The challenge is evident in the criteria imposed on these systems, which fail to adequately prioritize the IC site [9,66].

First, according to the literature, SM has been developed precisely for contextual adaptation and even reactive management of challenging situations [17]. In other fields, the key characteristics of SM are reactivity [3], active monitoring [1], situation control [2], and adaptive management [4]. Therefore, the following question arises: Why has SM been used and developed by these different IC companies and projects solely for the needs of project management without considering the needs of the site? At the IC project management level, it is very rare to see rapid and adaptive responses, such as those represented by SMs, unlike at construction sites where this is commonplace [67]. This situation raises another interesting question: How would the SA system and SM evolve from the perspective of the IC site? Would it potentially evolve to become more flexible than the needs of project management? Could something more flexible and agile than project management needs be developed to meet the needs of the site [68]? Should the development of the SA system and SM in IC be limited to the management level, or should it also be integrated at the site level to cater to the requirements of field workers, as proposed by Görsch et al. [66]? These important questions require further research.

Our findings provide a concern for the use of both SA and SM in the IC sector because the widespread IC site is usually the place where various situations are encountered during a construction project and where most deviations and volatility occur (e.g., in terms of progress, safety, quality, or cost) and need to be corrected promptly. Our results agree with those of Lundberg et al. [69], who found little adoption of digital technologies by key actors on construction sites. Our findings, however, suggest that the neglect of various IC site needs and the emphasis on project management may contribute to site actors' (i.e., the production team's) limited adoption of new technologies.

Inconsistent technology development can also lead to inconsistent use, one-sided communication, and a loss of benefits from user group coordination. For example, Lavikka et al. [70] highlighted this uncertainty and lack of knowledge among decision-makers on how to change practices when moving to digital systems in construction. Zulu and Khosrowshahi [71] argued that one possible reason for the lack of digital coordination is that, in construction companies, one department may be keen to promote digital innovation, while another department may not. Our findings suggest a broader phenomenon than differences in willingness to change within firms; indeed, our findings are drawn from several IC firms and projects that had nevertheless reached the same solution of not implementing digital SA and SM at the IC site.

At the core of the interviewees' responses was distrust of either the data or the contractors who produced it. This scenario may have arisen from the lack of clear policies in place to support digital capabilities and processes in these situations [72]. This finding leads to several interesting questions for further research. What motivates a stakeholder to monitor and share SA information, who benefits from that information, and how is SM as a management concept and the SA system as a system level formed and applied if these questions are not properly answered? From the findings, we speculate that the collection of data for the SA system and its use in SM are unfamiliar approaches in the IC sector, which would require some form of partnership and the identification of common benefits [72].

However, skepticism toward data can also arise as a natural response to a fundamental flaw in SM, as proposed by Darmer [21]. For instance, this flaw can be seen in the contradictory character of the outdated situation picture. Truth quickly becomes obsolete in SA systems as the situation evolves dynamically, particularly in a rapidly changing digital context, where information from various sources is continuously and swiftly flowing in. One might also question whether IC management should cease its attempts to anticipate the future and instead embrace its reactive nature. It is also possible that the development of SA systems in these investigated projects is progressing at a faster rate than their users can

keep up with and fully trust the information available to them. Therefore, it is imperative that future research prioritize acquiring a deeper understanding of the duration of time it takes for SA knowledge to age and become unnecessary and unusable for managing IC initiatives.

As in the literature review, the human-centered part of SM received the least attention among the interviewees' expressions, which reflects the tendency of both researchers and IC professionals to focus on applications rather than people [73]. The findings may also indicate a certain imbalance in the development of SA systems and the use of SM in IC. SA systems may have been developed with an emphasis on technology, while the human domain was neglected. What might this situation mean for the use of SA and SM in the IC sector? SA systems that are developed with a primary focus on technology, here without due consideration of the human dimension of SM, may lead to limited user acceptance [74]. An imbalance in the development of a sociotechnical system focusing on technology rather than people could prevent SA and SM systems from reaching their potential. In this respect, research on SM and SA in the IC sector could gain valuable insights from the healthcare sector, which has taken a different approach by not prioritizing digitalization and information technology in SM [27]. The emphasis appears to be mostly on individuals, teams, and human behavior in that context.

The present study has several limitations related to the generalizability of the findings. First, the study was conducted in one geographically limited area. Second, thematization and typification methods generally involve the interpretation and analysis of qualitative data, which can be subjective. A researcher's biases, perspectives, and preconceived notions may influence the identification and categorization of themes or types, potentially leading to biased results. The third limitation relates to the depth of the interviews; these sessions may lack depth in understanding complex phenomena because they rely on the participants' ability to articulate their experiences or perspectives. Some participants may not have been able to fully express their thoughts, emotions, or experiences through verbal communication, thus leading to incomplete or superficial data. These limitations were mitigated by reflecting on the research team's own biases and assumptions through peer discussion and cross-checking of the data, as well as careful documentation of the research data to ensure reproducibility. It should be emphasized that conducting interviews with experienced specialists in SM and the development and utilization of SA systems by these people could create sample bias. During these interviews, the viewpoints of the participants were most likely skewed in favor of SM. Therefore, the researchers mostly concentrated on analyzing the challenges rather than the benefits. The limited number of interviewees also affects the limited achievement of saturation, and future studies could benefit from additional interviews. However, the exploratory and revealing nature of the study limits its broader generalizability while revealing first-hand experiences of SM from the perspective of users of SA systems in IC.

6. Conclusions

The increasing complexity of ICs has led to the introduction of various knowledge-based management methods, such as SM, based on the concept of SA. The present study, based on 21 semistructured interviews with experts and managers from 11 different companies, explored how IC management professionals and SA experts perceive the use of SM in IC projects.

Our main findings indicate that IC professionals perceived the use of SM to be beneficial. The respondents felt that the SA system improved problem-solving skills, facilitated decision-making, and promoted open discussions among the IC management team. However, one main disadvantage of SM is that it is not applicable to construction sites because the SA system was created primarily for project management purposes. Among other benefits, the historical event data collected by these systems were useful. Some respondents criticized SM, however, noting a lack of (1) inclusiveness of site staff, (2) motivation of contractors to collect data, and (3) confidence in the accuracy of the SA data. The informants reported difficulty in motivating contractors to collect situational data for the system, which could be because of a misunderstanding of the purpose of data collection, the manual

nature of data collection, the perceived excessiveness of data collection, and the manual transfer of manually collected data to digital systems. The informants expressed skepticism about the SA system's information as a result of this costly and imprecise approach. In summary, the interviewees' responses indicate that sustaining SA necessitates active contact and regular verification of the information, including putting pressure on the contractors who provide the information.

The present study has also revealed an imbalance between SA and SM in IC projects, with technology and information being prioritized over the human element. The present study's findings suggest a shift toward a new research and practice trend in which SA technology in the IC sector is more focused on people. Further research and practice are needed to address the challenges and constraints associated with the use of SA technologies in the IC sector and ensure a more balanced approach that considers both technological and human aspects in a sociotechnical context.

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