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Exploring challenges in dimensioning safety buffers: an empirical study

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Abstract

Purpose – The purposes of this study were (1) to explore empirical challenges in dimensioning safety buffers and their implications and (2) to organise those challenges into a framework.

Design/methodology/approach – In a multiple-case study following an exploratory, qualitative and empirical approach, 20 semi-structured interviews were conducted in six cases. Representatives of all cases subsequently participated in an interactive workshop, after which a questionnaire was used to assess the impact and presence of each challenge. A cross-case analysis was performed to situate empirical findings within the literature.

Findings – Ten challenges were identified in four areas of dimensioning safety buffers: decision management, responsibilities, methods for dimensioning safety buffers and input data. All challenges had both direct and indirect negative implications for dimensioning safety buffers and were synthesised into a framework.

Research limitations/implications – This study complements the literature on dimensioning safety buffers with qualitative insights into challenges in dimensioning safety buffers and implications in practice.

Practical implications – Practitioners can use the framework to understand and overcome challenges in dimensioning safety buffers and their negative implications.

Originality/value – This study responds to the scarcity of qualitative and empirical studies on dimensioning safety buffers and the absence of any overview of the challenges therein.

Keywords Safety buffer, Buffer dimensioning, Dimensioning challenge

Paper type Research paper

Quick value overview

Interesting because: Dimensioning is deciding the size of safety buffers for inbound lead time, outbound lead time, inbound stock, outbound stock, capacity and queue lead time. Dimensioning is determined by judgemental methods or by calculation methods. The theory

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on dimensioning has focused on advanced calculations but without verification with empirical data. Something that in practice negatively affects the dimensioning of safety buffers but that is not reflected in the applied methods is called a challenge. These challenges represent a gap between theory and practice. This study presents a first step in bridging the gap between theory and practice by identifying these challenges and putting them into a comprehensive framework.

Theoretical value: The literature focuses on calculation methods for dimensioning but it was found that companies often use judgemental methods. While calculation method challenges have previously been identified in the literature this study adds challenges for judgemental methods. Furthermore, this study advances the theory by providing a comprehensive framework. This framework includes the implications, effects, impact and presence of challenges. Also, it was determined that the biggest impact is from challenges with responsibilities which was not previously known.

Practical value: Most of the identified challenges are of organisational and qualitative character which implies a need to underscore concern at high organisational levels. There are several things that managers can do to mitigate challenges. They can, e.g. (a) promote an understanding of used calculation methods to avoid informal practices to self-organise resilience that might lead to faulty dimensioning of safety buffers, (b) start measuring how much of the safety buffers are utilised to get more incentives for making adaptations and (c) clarify both overall and local responsibility that can reduce suboptimization.

1. Introduction

For decades, the literature has shown that to ensure their competitiveness and profitability (Browning and de Treville, 2021), companies focus on limiting excess resources to the greatest extent possible (Wang *et al.*, 2022) without compromising their delivery capability. However, as the capability to handle stochastic variations in supply and demand becomes increasingly critical in today's volatile business environment (Howells, 2020; Keskin *et al.*, 2022), equally critical is having added resources in the shape of safety buffers (Boulaksil, 2016; Hopp and Spearman, 2021; Wang *et al.*, 2022). Following Hopp and Spearman (2004), a safety buffer refers to additional resources maintained to absorb stochastic variations in supply and demand, with stochastic variations meaning random, short-term deviations from a stable baseline. To date, three major types of safety buffers have been identified—materials, capacity and lead time (Hopp and Spearman, 2004)—all of which Hedvall *et al.* (2023) have described in an overview. No matter the type, until the causes of stochastic variations are overcome, the size of a safety buffer and thus its capability to absorb variations will determine a company's delivery capability (Hedvall and Mattsson, 2022).

The literature on dimensioning safety buffers—that is, deciding the size of a company's additional resources to absorb stochastic variations—often focuses on advanced methods for dimensioning safety buffers and their underlying calculations but without examining their applicability in practice (Jonsson and Mattsson, 2019). Along similar lines, Gonçalves *et al.* (2020) have observed that, in such studies, surprisingly few researchers have verified advanced calculations with real-world data, much less implemented methods for dimensioning safety buffers in practice. Despite what those trends suggest, companies indeed confront several problems, difficulties, disadvantages and deficiencies—in a word, challenges—in their dimensioning of safety buffers. In that context, a challenge refers to something that negatively affects dimensioning safety buffers but that is not clearly reflected in methods for dimensioning safety buffers described in the literature. As a consequence of such challenges, the gap between theory and its practical application has become unnecessary large. To complement the extensive literature on methods for dimensioning safety buffers, this study concentrated on the application of those methods, namely by identifying practical challenges therein.

Given the lack of literature on challenges in dimensioning safety buffers, it would be useful to provide examples of such challenges as perceived in practice. The implications of those challenges and what types of negative effects they have on dimensioning safety buffers also need to be understood. Thus, the purpose of this study was twofold: (1) to explore empirical challenges in dimensioning safety buffers and their implications and (2) to organise the challenges into a framework. This study contributes to the literature on dimensioning safety buffers by providing a perspective oriented towards challenges in the practical application. The results are expected to lay a foundation for managers and researchers to improve dimensioning of safety buffers and further mitigate the identified challenges.

Following this introduction, the frame of reference describes the four areas in which challenges in dimensioning safety buffers can appear. Then a section that describes the method employed in this study is provided, followed by empirical findings to exemplify identified challenges. The discussion then situates our findings in the literature and a framework is developed, after which the conclusions, contributions and ideas for further research are presented.

2. Frame of reference: areas of challenges in dimensioning safety buffers

Following Swanborn (2010), a framework should provide guidance, beginning by generating a preliminary or pre-arranged structure for challenges expected to emerge in different areas. Such areas could be part of general decision-making with bounded rationality (Simon, 1990), in which decisions can be conducted in different steps. In this study, a framework with four areas representing four sequential steps is presented. First, decisions about dimensioning safety buffers have to be made. How those decisions are made and cognitive biases therein—that is, irrational beliefs that influence the ability to make decisions rationally (Calabretta *et al.*, 2017)—represent challenges in an area called *decision management*. Second, those decisions require responsibilities, including *responsibilities* for conducting the dimensioning and the performance measures connected to safety buffers. Third, there are challenges associated with the *methods for dimensioning safety buffers* used to make the mentioned decisions. In turn, those methods are based on *input data*, which represents a fourth area of potential challenges. Whereas the first two areas are of an organisational, qualitative character, the last two are of a technical, quantitative character. The following subsections characterise each area but not the challenges therein.

2.1 Decision management

Dimensioning safety buffers inevitably requires decision-making, whether in directly judging the size of safety buffers or in setting the decision parameters for calculation methods. At base, decision management refers to acquiring and processing information necessary for making decisions (Sanchez *et al.*, 2017) and coordinating processes (Kärkkäinen *et al.*, 2007). Past research has shown that, in practice, dimensioning safety buffers is often based on judgemental methods or involves aspects of manual decision-making as part of calculation methods (Jonsson and Mattsson, 2000). At the same time, it has also shown that no decision-making approach is superior but that all are more or less suitable to certain conditions (Flores-Garcia *et al.*, 2021). Decision-makers can be more or less rational (Calabretta *et al.*, 2017; Kim and Na, 2022), because cognitive biases can influence their decisions (Acciarini *et al.*, 2021). According to Kim and Na (2022), individuals perceive situations differently and thus run operations from different perspectives, always with the risk of overestimating or underestimating a situation. To overcome cognitive biases, business rules for decisions can be set (Fish, 2012).

2.2 Responsibilities

Responsibilities in dimensioning safety buffers refers to who is responsible for performing the dimensioning of safety buffers, which can involve one or multiple roles with one or more individuals with certain responsibilities. To avoid incorporating an unnecessarily high degree of safety, dimensioning one safety buffer requires considering how other safety buffers in the company are dimensioned. That dynamic relates to the allocation of safety buffers, meaning the set-up of various types of safety buffers in different parts of the company in consideration of material flows. An example of such allocation in the literature comes from Atan *et al.* (2016), whose findings align with recommendations holding that most safety buffers should be situated at the end of processes (de Kok and Fransoo, 2003).

2.3 Methods for dimensioning safety buffers

According to Jonsson and Mattsson (2016), dimensioning safety buffers is determined either by experience, using judgemental methods, or by calculations, using calculation methods. Judgemental methods involve manual assessments, in which the size of a safety buffer is determined based on experience and/or intuition. Although Hopp and Spearman (2021) have argued that judgemental methods should never be applied in planning under uncertainty, Jonsson and Mattsson (2000) revealed that 48% of companies in Sweden who participated in their survey reported applying judgemental methods in dimensioning safety stocks and safety lead times. Because judgemental methods naturally differ based on experience and circumstance (Flores-Garcia *et al.*, 2021), they cannot be described with any specificity, whereas calculation methods for safety buffers can.

Calculation methods have mostly been examined in relation to safety stock (e.g. Gonçalves *et al.*, 2020) and often in relation to different demand distributions (Jonsson and Mattsson, 2019). One example is Monte Carlo simulations for dynamic safety buffer sizes amid nonstationary demand patterns (Bahroun and Belgacem, 2019). Two types of calculation methods for safety stock frequently used in practice are based on what is called cycle service or demand fill rate service (Jonsson and Mattsson, 2016), both of which refer to a targeted service level and consider variation in demand and/or lead times.

Methods for calculating safety lead times are relevant when more stochastic variation exists in timing than in quantity (Whybark and Williams, 1976). According to Schneckenreither *et al.* (2021), most researchers have considered safety lead time analogously to the newsvendor problem and integrated it into calculations of safety stock. Nevertheless, safety lead times are often used in practice to cope with worst-case scenarios (Graves, 2011). Queue lead time is another type of safety lead time commonly used in planning manufacturing operations (Vollmann *et al.*, 2005). An example in the literature comes from Mattsson *et al.* (2019), who used a safety factor for queue lead time per work centre based on Kingman's equation (e.g. Hopp and Spearman, 2001).

By contrast, calculation methods for safety capacity are rarely described in the literature. Krajewski *et al.* (2010) have proposed using a percentage of gross capacity requirements per planning period, while Mattsson and Wikner (2017) have calculated safety capacity using a safety factor and, as a percentage, the desired period service.

2.4 Input data

Dimensioning safety buffers, with judgemental and/or calculation methods, is based upon various kinds of input data. When judgemental methods are applied, input data needed mostly concerns conditions such as expected market trends, internal guidelines or external disturbances. The success of calculation methods depends on the relevance of the input data to the specific method chosen (e.g. Gonçalves *et al.*, 2020). In the number-of-days method of calculating safety stock, for example, the input data are the number of days in stock, multiplied by the variable that affect buffer size (i.e. average forecasted demand per day).

Although performance measures are essential input data both for judgemental and calculation methods, such measures rely upon definitions that differ widely in type

(Stockmann *et al.*, 2021) and can be defined and measured in multiple ways (e.g. Forslund and Jonsson, 2010). Two central measures related to dimensioning safety buffers are service level and on-time delivery. Of the several metrics that actively define service level, the two most common involve using cycle service or demand fill rate service (Barros *et al.*, 2021). On-time delivery, or delivery precision, refers to the degree to which orders are delivered on time as promised. When used as input data for safety lead times, queue lead times and/or safety capacity, on-time delivery can be specified for items, orders or order lines, usually in units of weeks, days, hours or other time frames in which it should be delivered, received, controlled or consumed, all relative to the desired or confirmed date (Forslund and Jonsson, 2010).

3. Methodology

Considering that "advances in knowledge that are too strongly rooted in what we already know delimit what we can know" (Gioia *et al.*, 2012, p. 16), this study's goal was to generate knowledge from empirical data, hence having theory-building ambitions (Bryman and Bell, 2015). Case studies are often suitable for exploratory purposes; however the type of case study should be specified (Steenhuis, 2015). This study is categorised as an *inductive planned pragmatic case study with iterative components*. As already indicated, an *inductive* approach was used, to generate new insights on emerging theory that can be tested in subsequent research (Steenhuis, 2015; Eisenhardt, 1989). Substantive literature was used to describe the four areas of challenges, as encouraged by Steenhuis (2015), but *a priori* of established constructs (i.e. challenges in dimensioning safety buffers) were not available. Given the lack of existing measuring instruments, a quantitative survey was neither suitable nor possible to conduct (Swanborn, 2010). An empirical and participative research design was therefore adopted that also addresses methodological gaps (Gonçalves *et al.*, 2020).

Because data was collected and analysed cycle-wise along the project, where insights successively lead to additional data collection, the study involved *iterative* components (Steenhuis, 2015). For empirical data, multiple-case studies were conducted, which are particularly feasible in studies on complex phenomena in which people's perceptions are of interest (Swanborn, 2010). Unlike in the iterative pragmatic case-study method, all cases for the study were *planned* and selected at an early stage and increased credibility was sought by collecting the same data across all cases (Eisenhardt, 1989). A major sampling criteria was that companies should apply several types of safety buffers. Manufacturers with primarily complex make-to-order (MTO) products, following Whybark and Williams (1976), were expected to apply safety lead times and safety capacity as buffers, while manufacturers with make-to-stock (MTS) manufacturing strategy and wholesalers (i.e. purchase to stock) were expected to instead chiefly use safety stock. Such a broad set of cases was selected based on theoretical sampling given the potential to gain an increased understanding and fill conceptual categories (Steenhuis, 2015). In Table 1, an overview of applied and expected safety buffers is provided.

Additional criteria were that the companies should be knowledgeable in dimensioning safety buffers and provide necessary access. Data were collected from six cases, which is within the appropriate number of cases emphasised by Eisenhardt (1989). The cases' long-term involvement in a research project in Sweden, examining management of safety buffers, made them both informative and representative (Swanborn, 2010). Among the cases were four manufacturers of MTO products, one wholesaler to manufacturers and one MTS spare parts unit. All companies were large, which increased the probability of them having several safety buffers. Some of the cases are in the same supply chain, wherein Case E and Case C are suppliers to Case A1.

Empirical data connected to management of safety buffers in the cases were collected during a two-year period. In Table 1, details of data collection focusing on challenges are

Table 1.
Cases, within-case data and respondents

Case	Product (manufacturing strategy)	Applied and expected safety buffer Applied safety buffer that was not expected *Expected safety buffer that was not applied* (Dimensioning method, J: Judgemental method, C: Calculation method)	Respondent	Position	Data collection methods
A1	Gas turbines (MTO)	Inbound safety lead time (J) Outbound safety lead time (J) Queue lead time (J) *Safety capacity (J)*	R1A1	Manager Sales and Operations	Group interview (2:45 h), workshop (4 h), questionnaire
			R2A1	Stock Analyst	Group interview (2:45 h), workshop (4 h), questionnaire
			R3A1	Logistics/Capacity Planning Leader	Group interview (2:45 h), questionnaire
			R4A1	Capacity Planner: Manufacturing	Group interview (2:45 h), workshop (4 h), questionnaire
A2	Spare parts gas turbines (MTS)	Inbound/outbound safety stock (C) *Outbound safety lead time (J)*	R5A2	Demand Planning: Digital Development	Group interview (2:45 h), workshop (4 h), questionnaire
			R6A2	Demand Planning: Critical Components	Group interview (2:45 h), workshop (4 h), questionnaire
B	Luminaries (MTO)	*Inbound safety stock (C)* *Outbound safety stock (C)* Inbound safety lead time (J) Outbound safety lead time (J) Queue lead time (J)	R7B	Logistics Manager	Group interview (2:45 h), workshop (4 h), questionnaire
			R8B	Purchasing Director	Group interview (2:45 h)
C	Heat exchangers (MTO)	*Inbound safety stock (J)* Inbound safety lead time (J) Outbound safety lead time (J) Safety capacity (C) Queue lead time (J)	R9C	Supply Chain Manager	Interview (2:10 h), workshop (4 h), questionnaire

(*continued*)

Table 1.

Case	Product (manufacturing strategy)	Applied and expected safety buffer Applied safety buffer that was not expected *Expected safety buffer that was not applied* (Dimensioning method, J: Judgemental method, C: Calculation method)	Respondent	Position	Data collection methods
D	Aerospace components (MTO)	Inbound safety lead time (J) Outbound safety lead time (J) Safety capacity (J) Queue lead time (J)	R10D	Supply Chain Planner 1	Group interview (2:30 h), workshop (4 h), questionnaire
			R11D	Logistics Manager	Group interview (2:30 h), questionnaire
			R12D	Supply Chain Planner 2	Group interview (2:30 h)
			R13D	Supply Chain Manager	Group interview (2:30 h), questionnaire
			R14D	Fleet Monitoring Expert	Group interview (2:30 h), workshop (4 h), questionnaire
			R15D	Logistics Manager: Product Family 1	Group interview (2:30 h), questionnaire
			R16D	Logistics Manager: Product Family 2	Group interview (2:45 h), questionnaire
E	Manufacturing components (MTS)	Inbound/outbound safety stock (C) *Inbound safety lead time (J)*	R17 E	Developer Global Operations	Group interview (2:15 h), workshop (4 h), questionnaire
			R18 E	Purchasing Director: Nordic Region	Group interview (2:15 h)
			R19 E	Transport Leader/Process Developer	Group interview (2:15 h), workshop (4 h)
			R20 E	Purchaser	Group interview (2:15 h)

Source(s): Authors work

presented, consisting of semi-structured, company-specific group interviews, a joint interactive workshop and a questionnaire. Triangulation, using several different sources and researchers, was sought to improve the accuracy of interpretations and the credibility of the research. The combination of qualitative and quantitative data collection with different methods, together with the exploratory purpose are in line with a *pragmatic* approach (Steenhuis, 2015). Several different knowledgeable respondents with various job titles were of interest because multiple types of safety buffers were studied. Because contact persons in the case companies aided the identification of suitable respondents, the sampling was non-probabilistic and constituted an indirect form of convenience sampling known as snowball sampling (Bryman and Bell, 2015). Twenty respondents were ultimately interviewed. Table 1 also presents within-case data; main product, manufacturing strategy, applied and expected safety buffers, dimensioning methods and respondents, with the names of the companies anonymised. Within-case data on challenges are presented in section 4 and summarised in section 5.2.

Prior to all interviews, an interview guide was sent to the companies to discuss the questions internally and thus strengthen the likelihood of interviewing knowledgeable respondents. The interviews addressed practices in safety buffering extensively. Questions about challenges were asked, but the lack of literature on the topic meant that only open-ended questions about decision management, responsibilities, methods for dimensioning safety buffers and input data could be raised. All interviews were conducted virtually in observance of recommendations from authorities concerning remote work due to the COVID-19 pandemic. The interviews, all audio-recorded, were fully transcribed and synthesised into a summary for each company that was subsequently sent to each respondent for member check (Steenhuis, 2015) to verify that our perceptions of the respondents' statements made sense (Voss *et al.*, 2002).

All three authors independently coded the raw data (i.e. first-order concepts) into second-order themes or challenges for triangulation (Bryman and Bell, 2015). Cross-case comparing, seeking emerging patterns (Eisenhardt, 1989) and discussing coding resulted in 24 challenges. Thereafter, a presentation was given during a workshop at which respondents from all cases and the researchers gathered in person, for pandemic-related recommendations concerning remote work had then been rescinded. Questions were asked for clarification, to sort out ambiguities and to exchange knowledge (Gibbert and Ruigrok, 2010). In such a workshop, admitting challenges required extensive trust from the participants, which was established earlier in the research project. The data set was revised as a result of the workshop, that together with audio-recordings from interviews were the basis for analysis. This increased the confidence and reliability of the findings (Bryman and Bell, 2015). Because all data collection was conducted in Swedish, all texts were translated into English. Inspired by Gioia *et al.* (2012), within-case data were aggregated with the aim of conceptualising or theorising. Also following Gioia *et al.* (2012), after similar challenges were merged, only challenges mentioned in at least two cases and that could be theorised were retained. The final result was a framework with 10 challenges. The implications of each challenge were analysed based on experience and literature.

A questionnaire was lastly developed to gain deeper understanding of the relative impact and presence of the challenges in all cases, to expose all cases with the same emergent set-up of challenges and to further increase credibility (Steenhuis, 2015). It provided a short description of each challenge and two assessment questions—"To what extent has the following challenge impacted dimensioning of safety buffers at your company?" and "To what extent does the following challenge exist at your company?", assessed on a Likert scale ranging from 1 (no challenge/not at all) to 5 (a large challenge/to a very large extent; Bryman and Bell, 2015)—along with an open-ended question for opinions regarding each challenge. The questionnaire received a 75% gross response rate (i.e. 15 out of 20 answers) and provided answers that give indications either confirming or contradicting findings from the other data collection methods. Missing answers were traced to respondents who had left their positions and respondents with high management positions, not involved in the research project except for the interview. All respondents who were active throughout the project answered the questionnaire and the responses are therefore considered representative.

4. Cross-case findings

Of all safety buffers applied, safety lead time emerged in all six cases, safety stock in four cases and queue lead time in four cases. Safety capacity, however, emerged in only two cases (Cases C and D). For the wholesaler (Case E) and spare parts unit (Case A2), only safety stock and safety lead time were relevant, as expected. In Table 1 an overview of the applied safety buffers is provided, together with information on expected application based on the type of manufacturing strategy. Only Case A1 was missing an expected safety buffer (safety capacity), while the majority (4/6) utilise more types of safety buffers than expected.

Across the cases, several challenges in dimensioning safety buffers have been identified. Each challenge was assigned a three-part code, beginning with a "C" for challenge, followed by a letter indicating the area—"D" for decision management, "R" for responsibilities, "M" for methods and "I" for input data—and a serial number from 1 to 10 indicating the specific challenge. In the following subsections, each challenge is formulated as a proposition.

4.1 Challenges with decision management (CD)

4.1.1 CD1. Judgemental methods involve complex decisions: The respondents had a hard time describing the decision-making process for how safety buffers are dimensioned using judgemental methods given the nature of such methods. Complex judgemental methods seem to be at their worst in Case B, which bases its dimensioning of safety stock on 10 types of input data (i.e. lead time, demand, forecast, cost, space issues, supplier capacity, perceived market changes, number of withdrawals per year, inventory limits and full number of carriers). Case D bases its judgementally dimensioned inbound safety lead time on seven other types of input data (i.e. economic situation, ordering cost, stock interest, internal lead time, perceived variation in supply, variation in demand and supplier performance). The many aspects considered in the decisions signal a will to make judgemental methods advanced and accurate and reflect insights that the decisions are complex.

4.1.2 CD2. Judgemental methods involve person-dependent decisions: When calculation methods are applied, dimensioning safety buffers relies on calculations that are more or less objective and causal from input data in relation to a safety buffer size, whereas it became evident in all the cases that managers tend to make decisions based on personal experience, knowledge and biases in the use of judgemental methods. Because judgemental methods depend entirely on personal experience, which necessarily varies between decision makers, the sizes of safety buffers vary as well. R7B argued, however, that a benefit of using judgemental methods is the very possibility of considering experience.

4.1.3 CD3. Incentives to re-deciding safety buffering are few: Case A1, Case B, Case C and Case D revealed the tendency to become accustomed to using certain methods for dimensioning safety buffers and blind to alternatives. In Case A1, one type of safety lead time that was dimensioned by a CEO a long ago remains in practice and was described as "untouchable" (R1A1). When discussing safety lead time, R10D said, "We've always done it that way", to which R12D replied, "Exactly. So, we wonder how others do it". Such a lack of reflection, however, can inhibit the adjustment of safety buffers. In Case D, R10D claimed that as long as the company's delivery capability remains sufficient, complacency is the norm.

Only when requirements to decrease tied-up capital or reduce lead times come from top management do incentives to decrease safety buffers emerge. By comparison, R15D explained, “We realised while reviewing safety lead times that were far too long, that they were based on a perceived risk from three years ago but had not been adjusted”. To that, R16D added, “It’s not really as adaptive as one would hope”.

4.2 Challenges with responsibilities (CR)

4.2.1 CR4. Many individuals are unclearly responsible for local safety buffers: Local safety buffers refer to each identified type of safety buffer within a company. Among the cases with many roles responsible for dimensioning safety buffers are Case C and Case E. Case C has plant manager, production manager, planner and supply chain manager responsible for safety capacity, while Case E has purchasing manager, operations manager and CEO responsible for safety stock. By comparison, Case A1 maintains two different inbound safety lead time buffers: one overseen by a stock analyst, the other overseen by the logistics and assembly staff. It should be considered that the job titles of the respondents are highly company-specific, meaning that respondents with different titles could have similar responsibilities on the job and vice versa. However, several individuals are nominally responsible for local safety buffers and it is then possible that none in fact take responsibility.

4.2.2 CR5. No one has an overall responsibility for safety buffers: The six cases revealed approximately 20 different safety buffers, with at least two safety buffers per case. Whereas the interview questions addressed the responsibility for each local safety buffer, the workshop focused on the responsibility for the overall selection and allocation of safety buffers in each case and showed that such overall responsibility has been lacking in all cases. Consequently, the dimensioning of local safety buffers is conducted in silos without any recognition of how it affects and contributes to the total safety.

4.2.3 CR6. Safety buffers are decoupled by top management’s responsibilities: It was shown in the cases that safety buffers are dimensioned in comprehensive ways by local middle managers. Simultaneously, dimensioning safety buffers can be decoupled and even restricted by top management’s responsibilities. After all, safety stocks and safety lead times are directly and indirectly connected to tied-up capital, while safety capacity is directly and indirectly connected to resource utilisation, and all have a direct impact on delivery capability. Though top management may pursue low tied-up capital, high delivery capability and high resource utilisation, achieving that trifecta remains a challenge in practice. As R12D mentioned, “We would like to adjust [our safety buffers], but we usually can’t afford it”. R15D added, “I would say that it’s financially driven, but it also differs over the year”. Meanwhile, R10D explained the lack of discussions about the trade-off between objectives and that such decoupling between responsibility and dimensioning leads to a “jerkiness” in dimensioning safety buffers. That is, different objectives receive attention from top management over time and prioritisation naturally occurs.

4.3 Challenges with dimensioning methods (CM)

4.3.1 CM7. Calculation methods have limited availability: When enterprise resource planning (ERP) systems do not include adequate calculation methods for dimensioning safety buffers, and no other system support is accessible, only judgemental methods remain. Among the safety buffers identified in the cases, only five are dimensioned with a calculation method. As expected, representatives of Case A2 and Case E—the spare parts unit and the wholesaler, respectively—reported dimensioning their safety stocks using calculation methods. Safety lead time and queue lead time are dimensioned with judgemental methods in all cases. R9C confessed, “There are no advantages [with judgemental methods]. It’s an assessment sport, like figure skating . . . but that’s the only thing that we can do [with some of the safety buffers]”.

4.3.2 CM8. The connection between calculation methods and delivery capability remains unclear: A central challenge identified in the interviews was the unclear connection between calculation methods and delivery capability. Case A2, for instance, calculates safety stock using cycle service. The respondents in Case A2 explained, however, that they have tried several different calculation methods over the years but never understood why the expected delivery capability was not reached. By contrast, Case E calculates safety stock using demand fill rate service. Their ERP system dimensions safety stock every day based on demand but the decision parameter (i.e. service level) is seldom updated, thereby making the dimensioning of safety buffers less connected to delivery capability.

4.4 Challenges with input data (CI)

4.4.1 CI9. The quality of input data in calculation methods is low: In Case E, the calculation method was criticised by employees; however, the culprit was found to be low-quality input data, not anything regarding the ERP system's calculations. According to R17 E and R18 E, an important lesson learned has been the significance of securing quality input data when using calculation methods.

4.4.2 CI10. Input data are not defined clearly enough: After a lecture on performance measurement in the project, R1A1 recalled that "it suddenly became crystal clear that we use percentages everywhere, without stating how those percentages are defined". During discussions of on-time delivery, it became similarly clear that respondents were specifying measurement objects, time units, measurement points and reference points differently. In other words, apples and oranges were being compared. R1A1 realised that such misinterpretations apply internally as well, because input data can change over time.

5. Discussion

In this section the identified challenges are linked to literature, followed by presenting a framework of challenges in dimensioning safety buffers and a concluding discussion.

5.1 Theorizing the identified challenges

Starting with *decision management*, it was shown in the cases that a lot of input data are considered in judgemental methods for dimensioning safety buffers (CD1). According to R10D, no clear guiding principles are available for dimensioning safety capacity and safety lead time, even though cognitive biases may become prominent without guiding principles for decision making (Fish, 2012). One implication is that weighing such complex input data together into a decision seems impossible; another is that judgemental methods are extremely time-consuming to apply, which discourages companies from updating them frequently. Judgemental methods naturally involve person-dependent decisions (Calabretta *et al.*, 2017), see CD2, that are based on personal experience, values and biases, in line with findings by Acciarini *et al.* (2021). At the same time, such methods imply the difficulty of transferring the experience relied upon to other employees (Flores-Garcia *et al.*, 2021). Four of the cases revealed that there is a tendency to become accustomed to current setup of safety buffers as the incentives to make changes are few (CD3). Those revelations do not support findings by Vanichchinchai (2022), who has stressed the need to react to changes in supply and demand and overcome effects of uncertainty to sustain competitiveness. R7B, for example, mentioned that their company's safety lead time is based on the worst-case scenario, with the implication of unnecessarily high safety buffers, as Graves (2011) similarly found. These findings align with Kahneman's (2011) observation that common cognitive biases include loss aversion and the risk of not striving for better results. At the workshop, the respondents described additional implications including that focus continually shifts to acute problems, that safety buffers systematically increase quite easily and that safety buffers with unduly large sizes are not decreased.

When it comes to *responsibility*, the cases showed that many individuals are involved but without clear responsibility for the local safety buffers (CR4). Case D utilises safety lead time at several points along the material flow, in line with Atan *et al.* (2016), but with several individuals that are nominally responsible. This makes it possible that none in fact take responsibility. The lack of responsibility is fully absent in the cases when it comes to an overall responsibility for safety buffers (CR5). Hence, dimensioning of safety buffers is performed in silos and redundancy may emerge as different types of safety buffers can provide the same absorption of stochastic variations. Chaturvedi and Martínez-de-Albéniz (2016) have shown, for example, that both safety stock and safety capacity increased the responsiveness of a manufacturer and should therefore be jointly dimensioned, or else the overall safety becomes excessive. However, the theoretical support for safety buffer allocation and joint dimensioning remains scarce. This is closely related to CR6 that appeared in several cases, namely that safety buffers are decoupled by top management's responsibilities. Different objectives receive attention from top management over time and prioritisation naturally occurs, for no method for dimensioning safety buffers can provide optimal results in every dimension, as Stockmann *et al.* (2021) also found while investigating robustness assessments in production systems. Guidance and support from top management is thus essential for succeeding in dimensioning safety buffers, not least as a means of cultivating the motivation to learn and adaptability to change, as mentioned by Sun *et al.* (2022).

Two challenges were identified in the cases connected to *dimensioning methods*. First, that there is a limited availability of system support for adequate calculation methods (CM7). For dimensioning safety buffers, an implication is that all built-in knowledge and calculation formulae in calculation methods for safety stock (e.g. Gonçalves *et al.*, 2020; Bahroun and Belgacem, 2019; Jonsson and Mattsson, 2019), safety lead times (Schneckenreither *et al.*, 2021; Mattsson *et al.*, 2019) and safety capacity (e.g. Mattsson and Wikner, 2017; Krajewski *et al.*, 2010) remain unutilised. Such low utilisation could also be explained by the preconditions and assumptions that the methods for dimensioning safety buffers built on are not always fulfilled in practice. Second, that there is an unclear connection between calculation methods and delivery capability (CM8). When calculation methods are applied, dimensioning safety buffers relies on more or less objective calculations (Calabretta *et al.*, 2017), but the decision parameter for the calculation is not directly related to the desired level of delivery capability. R18 E explained that no manual adjustments of calculated safety stocks are allowed. Thus, when delivery capability has been too low and there is a lack of understanding for how the calculation of safety stock works, employees working with ordering have used workarounds—for example, by placing orders earlier than recommended—that create safety lead time. Such instances of developing informal local practices to cope with uncertainty, as described by Gayer *et al.* (2022), underscore the importance of promoting an understanding of how safety buffers should be calculated in a company, chiefly to avoid the implication of additional or faulty dimensioning of safety buffers. Another implication is that adjusting the dimensioning of safety buffers using calculation methods is difficult without a thorough understanding of the calculations and underlying assumptions in the calculation methods used.

The empirical data also revealed problems with low quality of *input data* in calculation methods (CI9), which have negative implications for accurate calculations (Gonçalves *et al.*, 2020). Gonçalves *et al.* (2020) have further argued that future methods for dimensioning safety buffers should better account for input data, because the output from a method is only as good as its input. Keskin *et al.* (2022) have additionally highlighted the importance of not only the quality but also the quantity of input data for improvements, especially in shifting conditions. Input data can be defined in multiple ways and each definition has ramifications (Stockmann *et al.*, 2021), which is not clearly described in several cases (see CI10). Different measurements were faulty compared and that mismatch has implications as difficulties to communicate input data (e.g. on-time delivery as a metric) with customers and suppliers and in knowledge exchange with other companies. To ensure that a safety buffer enables the desired delivery capability, it is important to define input data in line with that reality (Barros *et al.*, 2021, Forslund and Jonsson, 2010). If the understanding of input data in calculation methods and the applied input data in practice do not correspond it inevitably has the consequence of faulty dimensioning of safety buffers (Barros *et al.*, 2021).

5.2 A framework of challenges

Having qualified ten challenges by links to literature, a framework was developed. Table 2 consists of eight columns, described from left to right. The 10 challenges are first classified into the four areas outlined in the frame of reference (column 1), which also made sense after the empirical research. Each challenge is mentioned and related to judgemental or calculation as dimensioning method (2). The cases in which each challenge was acknowledged are thereafter presented (3) and each challenge is supported by an exemplifying quotation (4). All challenges were shown to have negative implications (5) and direct and/or indirect effects (6) on dimensioning safety buffers. A direct effect on safety buffer sizes means that they become faulty dimensioned—that is, more or less than required (i.e. both in size and number of safety buffers). An indirect effect, by contrast, means a delay in dimensioning, such that the safety buffer size is not adjusted often enough. The results of the questionnaire are then presented as mode, minimum and maximum values for the impact (7) and presence (8) of each challenge.

When it comes to impact, CR4 and CR5 are the challenges with the highest mode (i.e. 5; see Table 2). The group of challenges with responsibilities has the highest mode among the different areas of challenges and seems to have a high impact on dimensioning safety buffers. The impact connected to responsibilities was expressed by R9C as follows: “Symptoms come before facts. The budget has a tendency to override the facts”. In contrast, R4A1 wrote the following regarding responsibilities: “Each responsible [for different areas and/or safety buffers] tends to build safety buffers to reach their targets when no one has an overall responsibility for safety buffers. It can result in an unnecessarily large total amount of safety buffers for the company.” On the other end of the spectrum are the challenges with input data, with the lowest mode (i.e. 2) for both CI9 and CI10. That result suggests that the impact of high-quality input data and clear definitions are not acknowledged, which exerts a direct impact on dimensioning safety buffers, especially for calculation methods. However, the impact might not be considered to be as great for judgemental methods, as used in most cases in the study, hence the low assessment regarding impact.

All challenges seem to be present for most safety buffers in the cases, except CI9 and CI10, which have a mode value of 2 (2 and 3 equally for CI9). That circumstance could also be explained by the high share of judgemental methods applied, in which CI9 is applicable for calculation methods. R6A2 explained their situation in which a calculation method is used: “Our master data are not always correctly updated, meaning that decisions are made on misguided information”. More surprisingly is the low mode value (i.e. 2) for CI10, which implies that input data are considered to be defined clearly enough for most safety buffers. That outcome contradicts what several cases revealed, in which performance metrics were discussed as being comparable, although the underlying definitions for those metrics differed in details. As a consequence, CI10 can be underestimated in such cases because definitions can vary widely (Stockmann *et al.*, 2021). R1A1 wrote: “It has become rather clear in this

Table 2.
Framework of challenges in dimensioning safety buffers

Area	Challenge (in dimensioning method)	Acknowledged in cases (based on interview/workshop)	Supporting quote	Implications	Effect	Impact* * = *mode* *(min-max)*	Presence* * = *mode* *(min-max)*
Decision management	*CD1:* Judgemental methods involve complex decisions (judgemental)	B, D	"There are a whole lot of ingredients considered . . . the cost for purchased components, how much space they take, supplier capacity . . . and how long lead times we have." (R8B)	"Impossible" to weigh multiple types of input data together Judgemental methods are time-consuming Complex judgemental methods mean low updating frequency	Direct and indirect Indirect Direct and indirect	4 (2–4)	4 (2–4)
	CD2: Judgemental methods involve person-dependent decisions (judgemental)	A1, A2, B, C, D, E	"We know that individual assessments based on different risks can result in very different safety buffer levels as we all are different from each other." (R13D)	Difficult to transfer experience to other employees	Direct and indirect	4 (1–5)	4 (2–5)
	CD3: Incentives to re-deciding safety buffering are few (calculation and judgemental)	A1, B, C, D	"I am responsible for it [dimensioning outbound safety lead time], but I don't do it continuously, only if I have to." (R9C)	Unnecessarily high safety buffer sizes Easier to increase than to decrease safety buffer sizes	Direct Direct	4 (1–4)	4 (1–4)
Responsibilities	*CR4:* Many individuals are unclearly responsible for local safety buffers (calculation and judgemental)	A1, C, E	"We have recurring meetings to discuss if we might change the service level . . . among others, me, the operations manager and the CEO." (R18 E)	No one has the responsibility for local safety buffers	Direct and indirect	5 (1–5)	3 (1–5)
	CR5: No one has an overall responsibility for safety buffers (calculation and judgemental)	A1, A2, B, C, D, E	"I would say that we do not work actively with it, so it is a bit unclear today who is [overall] responsible." (R4A1)	Unnecessary high total safety buffering	Direct	5 (1–5)	5 (1–5)
	CR6: Safety buffers are decoupled by top management's responsibilities (calculation and judgemental)	A1, A2, C, D	"I do not see any clear forum where a balance between delivery precision, tied-up capital and resource utilization is strived for. In different times it tends to be a focus on one of these three from top management." (R10D)	Jerkiness in dimensioning safety buffers over time	Direct	4 (3–5)	3 and 4 (2–5)

(*continued*)

Table 2.

Area	Challenge (in dimensioning method)	Acknowledged in cases (based on interview/workshop)	Supporting quote	Implications	Effect	Impact* * = *mode* *(min-max)*	Presence* * = *mode* *(min-max)*
Methods	*CM7:* Calculation methods have limited availability (calculation)	A2, C, E	"It is always good to calculate things, to have a theoretical value. To guess gives some preservation but it is not always right. I would rather get an analytical view on it, to get an objective assessment." (R9C)	Built-in knowledge and calculation formulae in calculation methods remain unutilised	Direct and indirect	4 (2–5)	4 (2–5)
	CM8: The connection between calculation methods and delivery capability remains unclear (calculation)	A2, E	"We have tried several different calculation methods, tried to look at demand during lead time, desired service level [delivery capability] and tried to make adjustments depending on the cost for materials . . . we have also tried a simulation model to consider safety stock and the total cost in relation to what service level it [the size of the safety stock] leads to." (R5A2)	Additional and/or faulty safety buffer sizes Difficulties in adjusting safety buffer sizes	Direct Direct and indirect	4 (2–5)	4 (2–5)
Input data	*CI9:* The quality of input data in calculation methods is low (calculation)	A2, E	"There have been complaints that the system has not been good, but there is nothing wrong with the system, we have created problems ourselves when we have added faulty input data into the system, as inaccurate lead times, inadequate forecasts" (R18 E)	Less accurate dimensioning of safety buffers	Direct	2 (1–5)	2 and 3 (1–5)
	CI10: Input data are not defined clearly enough (calculation and judgemental)	A1, C, E	"We have decided to have 98% [service level] out to customers throughout." Service level was here discussed as defined in the same way for inbound and outbound, which was later found to be defined differently, e.g. last confirmed vs first confirmed and with different tolerance levels to count as on time in full. (R17 E)	Difficulties in communicating input data externally, internally and over time Faulty dimensioning of safety buffers	Direct and indirect Direct	2 (1–5)	2 (1–5)

Source(s): Authors work

project that things are unclear, especially when we twist and turn what governs safety buffers and what input data we should use". CR5 is the only challenge with a mode value of 5 for presence, which confirms findings from the workshop that an overall responsibility for safety buffers is missing. When comparing the cases in which the challenges were acknowledged during interviews (column 3), with the presence as replied in the questionnaire (column 8), it is noted that the latter is higher. This can be expected as it can be easier to acknowledge challenges when ten formulated challenges are presented to react on, as for the questionnaire, compared to the interviews that were more inductive and open. The questionnaire therefore represents interesting insights, where the same data is collected across all cases (Eisenhardt, 1989).

The questionnaire also revealed that mode values for impact and presence of each challenge are similar, that is, for CD1, both impact and presence are 4. If impact and presence are used to rank the four areas for dimensioning safety buffers, then responsibilities are the highest or most important, decision management and methods are in the middle, and input data is the lowest or least important.

5.3 Concluding discussion

Several challenges were found in each case, with implications of both direct and indirect negative effects on dimensioning safety buffers. Those negative effects can amplify each other and be translated into lower (Hedvall and Mattsson, 2022) or higher (Vanichchinchai, 2022) delivery capability, compromised competitiveness and profitability (Browning and de Treville, 2021). Most of the challenges, including those in decision management and responsibilities, were of an organisational, qualitative character, thereby implying a need to underscore concern for and interest in dimensioning safety buffers at higher organisational levels. According to Keskin *et al.* (2022), safety buffers are of strategic importance and should receive attention from top management, for they permit an organisation to accommodate changes and leverage delivery capability. Along those lines, this study confirms and extends Abu *et al.*'s (2022) findings that knowledge, cognitive biases and a lack of interest and support from top management play significant roles and are part of the identified challenges for dimensioning safety buffers as well. Top management may shift priorities between contradictory objectives over time. The short-term focus on a certain objective tends to be prioritised over the long-term balance of all objectives, with the implication that dimensioning safety buffers can be decoupled from absorbing today's volatile stochastic variations in supply and demand, as argued by Howells (2020). In addition, Ghobakhloo *et al.* (2022) found barriers in the transition to Industry 4.0 that relate to top management's lack of support and competency, which also applies to the identified challenges that play an important role in enabling possibilities to adapt Industry 4.0 technologies in dimensioning safety buffers.

Many safety buffers are applied in the cases and unduly high safety buffering has been repeatedly an implication. Hedvall *et al.* (2023) additionally found a lack of holistic view in the selection of safety buffers, which also leads to having too many and too large safety buffers, ultimately affecting learning in the organisation because root causes are in disguise (Kim and Na, 2022). At the same time, it is important to not decrease safety buffer sizes without due cause, for blindly decreasing safety buffers may have unintended outcomes (Wang *et al.*, 2022). After all, safety buffers directly impact delivery capability and it is therefore important that the challenges in dimensioning safety buffers are handled accordingly.

The utilisation of calculation methods in the cases was found to be low. Only five safety buffers are dimensioned based on calculation methods, and all cases use judgemental methods. Those figures far exceed the 48% of the companies observed in a survey study from more than 20 years ago (Jonsson and Mattsson, 2000), which is a bit surprising as it could be expected that the technological development since then would lead to calculation methods as being more dominant. Hopp and Spearman (2021) argue that judgemental methods should, at least theoretically, not be applied in planning under uncertainty. The fact that practical applications in our study deviates from this provides interesting insights, theoretically and empirically, on the challenges that can be expected related to the use of judgemental methods. Questions arise about whether the low utilisation of calculation methods can be explained by the identified challenges, including the limited availability of calculation systems, the unclear connection between calculation methods and delivery capability and the lack of an overall responsibility for safety buffers.

The challenges related to calculation methods are mainly challenges with the dimensioning method, while judgemental methods are mainly connected to challenges with decision management. Both methods were found to relate to challenges with responsibilities and input data. When analysing the four areas, responsibilities was identified as particularly important. The areas were found to be linked to each other in different ways. e.g. within-area reinforcement, as in decision management when judgemental methods involving complex decisions reinforce person-dependent dimensioning. Other challenges counteract other cross-areas, such as between the challenge of top management involvement, which characterises dimensioning of safety buffers as jerky and short-term (i.e. responsibilities), and the challenge of few incentives to adjust safety buffers in the long term (i.e. decision management). That setback can relate to a cognitive bias of not reflecting on accustomed ways of dimensioning safety buffers or contentment with an already high delivery capability (Hopp and Spearman, 2021), emphasising the importance of finding an appropriate way to follow up on the degree to which safety buffers are utilised.

6. Conclusions, contributions, limitations and future research

The purpose of this study was to explore empirical challenges in dimensioning safety buffers, as well as their implications and to organise them in a framework. Ten challenges in dimensioning safety buffers have been identified in four areas: decision management, responsibilities, methods and input data. The challenges have implications with both direct and indirect negative effects on dimensioning safety buffers and are mainly of an organisational and qualitative character. Personal experiences, or intuition, tend to be a natural part of the decision-making when dimensioning safety buffers, especially when there is a lack of business rules (as suggested by Fish, 2012), division of responsibilities and system support. Most challenges had a high mode value for both presence and impact, which emphasises the strategic importance of addressing challenges in dimensioning safety buffers and of receiving support from top management.

The developed framework is a contribution to the literature on dimensioning safety buffers, since no such overview on challenges with dimensioning safety buffers in practice, to our knowledge, has been published. Other contributions are the indication of unduly high safety buffering in the cases and, by linking applied safety buffers to manufacturing strategy, the identification of safety buffers that were not expected. Other contextual variables could be addressed in further research. Along similar lines, this study has responded to the lack of research on the applicability of methods for dimensioning safety buffers in practice (Jonsson and Mattsson, 2019) and empirical studies based on real-world data (Gonçalves *et al.*, 2020). The study therefore complements the research landscape of quantitative simulation and mathematical modelling. Beyond that, the study expands the literature on dimensioning safety buffers by furnishing qualitative insights into practice in which methods for dimensioning safety buffers are associated with several challenges. That expansion can contribute to the understanding of researchers who study dimensioning of safety buffers, to become more aware of and address the identified challenges in upcoming research and complement the prevailing focus on developing more advanced calculation methods. The gap between theory and application in practice can then be expected to decrease by addressing the identified challenges in the development of methods for dimensioning safety buffers. As for our work's practical contributions, practitioners can use the developed framework to better understand and overcome such challenges as well as their negative implications. Practitioners can use the framework reactively to acknowledge challenges prevailing in their companies and the inevitable implications, as a starting point in developmental work to avoid the challenges and the negative implications and effects that follow. The framework can also be used proactively to prevent challenges from emerging. Practitioners can acknowledge that challenges are often of organisational character, which to some extent can be handled without large investments. On a societal level, the appropriate use of limited resources is highly valid. The findings can be used in teaching to emphasise that the theoretically recommended calculation methods are not always applied in practice as expected. The challenges highlight the complexity of dimensioning safety buffers in practice, which is seldom portraited in textbooks. It also shows that more attention could be needed, theoretically and empirically, in at least 3 out of 4 areas (i.e. decision management, responsibilities and methods) based on a considered high impact on the dimensioning of safety buffers.

Some limitations of the findings indicate several avenues for future research. First, the challenges identified in this exploratory study, all formulated as propositions, should be tested in a broader survey study to create new, robust theory. Such research would need to carefully identify accurate respondents, for this multiple-case study has revealed that various positions and roles across organisations are involved in dimensioning safety buffers. Second, despite several identified challenges with decision management, responsibilities, methods and input data involved in dimensioning safety buffers, without knowledge about their relative presence beyond our cases, they wait to be mitigated. To be clear, it was beyond the scope of this study to address such mitigations; nevertheless, it is an interesting avenue for further research that can leverage the framework. Third, some case companies are customers and suppliers in the same supply chains and rather fascinating discussions with an expanded supply chain scope were held at the workshop, concerning how a supplier dimensions their (outbound) safety buffers when a customer dimensions their (inbound) safety buffers. This would accommodate an innovative approach to dimensioning safety buffers in supply chains, enabling a more holistic perspective and investigating the combined effect of different safety buffers, which are important questions for integrated supply chain management. Fourth, a work process for dimensioning safety buffers, both for judgemental and calculation methods, is lacking in the studied companies. Further systematising dimensioning of safety buffers, including routines to follow up on delivery capability and make adaptations in decision parameters as input data and dimensioning, could reduce cognitive biases (Kim and Na, 2022). Such enhancements can be based on adaptive control, in which a company's adaptability indicates its ability to react to changing conditions (Keskin *et al.*, 2022). The companies all expressed interest in such adaptive dimensioning of safety buffers, thereby potentially signalling another challenge—namely, outdated practices and behaviours—as also identified by Keskin *et al.* (2022). Fifth, the identified challenges need to be considered in developing a standardised routine for adaptive dimensioning of safety buffers, preferably with guidelines to facilitate employees' commitment and top management's support, as advised by Abu *et al.* (2022) in response to cultural challenges. Such consideration is particularly important, for it does not matter how good a routine is if individuals who make decisions do not use it as intended. Sixth, the impact and presence of each challenge indicated a spread in the answers. When and why certain challenges are present and influential are potential avenues for further research. Last, a more conventional application of the multiple-case method would enable further research, including a deeper within-case analysis, that enable explanation of why challenges appear in companies with different contexts and characteristics.

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