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OBSERVING SMES WITH TECHNOLOGY ADOPTION GLASSES THROUGH SYSTEMS ENGINEERING LENS

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Abstract

Hi-tech small and medium enterprises (SMEs) are facing many organizational challenges such as lack of resources including knowledge, competent workforce, managerial training, and experiences. Additionally, SMEs encounter engineering management challenges including inefficient decision-making, inability to adapt changes and lack of customers understanding. Technical support is required to cope with these challenges. Systems engineering (SE) can contribute to resolve growing challenges of complexity and enhance organizational efficiency in this context, although SE adoption is a challenge itself. Primarily SE is employed by large enterprises to manage complexities. The main objective of this study is to investigate the relations among the challenges faced by hi-tech SMEs, the expected benefits and barriers while trying to solve these challenges by adopting SE, and the existing best practices that can facilitate this adoption. Three mind-maps were developed a) challenges faced by hi-tech SMEs, b) potential benefits and challenges to adopt and implement SE, and c) ways to facilitate adoption. These maps converge into an impact model that highlights the important factors to be improved with SE knowledge and tries to overcome barriers associated with adoption processes. Authors argue that technology adoption theories and techniques can provide support to make SE more adoptable in the case of hi-tech SMEs. Therefore, the presented impact model can help hi-tech SMEs to decide on strategies to use SE to solve some of their engineering management challenges.

Keywords: decision support, engineering management, organizational challenges, small and medium enterprises, systems engineering, technology adoption

JEL codes: M15, 014

1. Introduction

Small and medium enterprises (SMEs) are considered a pillar of a country's economic growth. They contribute to the economic development and provide support in regional, cultural and developmental aspects as well (Palmieri, 2007). The European Union (EU) define SMEs as firms

employing fewer than 250 employees with the annual turn over less than or equal to 50 million euros or 43 million euro in the balance sheets (European Commission, 2003). SMEs represent approximately 99.8% of Europeans businesses (Alessandrini *et al.*, 2019) and has the employment share up to 65% in 2020 (Hope *et al.*, 2021). SMEs contributes to the economic value addition, growth, and sustainability of society. Along with economic and social benefits, hi-tech SMEs are facing a unique set of issues, that requires assistance as compared to large enterprises. Some of the identified issues in SMEs are market failure, and structural fields such as finances, research, innovation, and environmental regulations (Antoniuk *et al.*, 2017). Rigidity in labor market, lack of management and technical skills, and limited knowledge of opportunities are the kind of structural barriers that may appear at SMEs, as well (Yoshino, 2016). Moreover, these challenges may contribute to issues related to organizational decision-making at SMEs. SMEs are under pressure to adopt and use modern ways to overcome these hurdles more intensively. Systems Engineering (SE) is a potential way forward in this perspective, that can provide tools, techniques, processes, and methodologies to provide better decision support to overcome these challenges. This paper examines issues and challenges faced by SMEs and potential of SE implementation highlight possible hindrance in SE implementation by considering technology adoption challenges.

To address the growing challenges of complexity and enhance organizational efficiency, there is a widely accepted belief that the concept of Systems Engineering (SE) has expanded to encompass a more comprehensive approach. Hi-tech SMEs require access to sophisticated technical solutions that support various technical system-level functions. These include concept creation, performance assessment, architecture development and risk assessments etc. Moreover, SMEs need to address organizational functions related to design and development phases from conception to retirement along with effective stakeholder communication and record management. It includes both external stakeholders such as customers and users, as well as internal cross-disciplinary engineering teams. According to INCOSE (Walden *et al.*, 2015) SE is defined as

“a transdisciplinary and integrative approach to enable the successful realization, use, and retirement of engineered systems, using systems principles and concepts, and scientific, technological, and management methods.”

SE aims to fulfill customer needs and requirements by defining them early in the development cycle, documenting them, and ensuring their integration into the design and validation process of the system. It spans both technical and business needs of stakeholders to ensure the end-product is of high quality and meets user needs and specifications. Additionally, SE offers necessary competencies for effective project management. i.e. “shared leadership, social competence and emotional intelligence, communication, skills in organizational politics and the importance of visions, values, and beliefs have emerged as competencies that are required from project managers in complex environments” (Thomas and Mengel, 2008).

The foundations of SE can be traced back to 1930s, but it saw considerable growth in the 1950s when the Department of Defense DoD¹ required the delivery of military projects on time, within budget, and these critical aspects; 1) achieve long term objectives and 2) effective stakeholder management (Locatelli, Mancini and Romano, 2014).

According to (Honour, 2004) SE implementation requires about 15-20% of total project effort for optimal results. This approach has been adopted by large industries such as automobile and aerospace, as well as complex organizations like the DoD, to address organizational complexities. However, there is a basic difference between SMEs and large industries in terms of finances and human resources. Furthermore, SE is often regarded as an expensive solution in SMEs.

Despite the benefits of SE to manage complexities, there has been limited discussion in literature on SE adoption and challenges faced by SMEs in the adoption process. Researchers have investigated the behavior of stakeholders such as end-users and customers and identified three key challenges: entrepreneurial, technological, and administrative (Yanes-Estévez, García-Pérez and Oreja-Rodríguez,

¹ The Department of Defense (DoD) is an Executive Department of the United States government responsible for overseeing and coordinating all agencies and functions of the government relating to national security and Armed Forces. DoD has played a significant role in developing various management practices and tools, such as the SE, which are primarily used both in military and civil settings. These techniques can be traced back to the DoD's original research and development efforts.

2018). The adoption process of new technology at hi-tech SMEs can be influenced by the role of human resources and can present numerous challenges.

The aim of this paper is to investigate the challenges faced by SMEs and explore the field of systems engineering, to mitigate/overcome these challenges. This includes challenges may be inflicting by SE adoption/implementation at SMEs.

The structure of this paper is as follows: Initially, we describe the research methodology used for data collection. This is followed by an overview of existing literature on the challenges faced by SMEs, systems engineering competencies, and the challenges related to technology adoption. Subsequently, the findings are presented in Section 3, to highlight the gap in existing literature. Finally, we conclude by addressing the limitations of this study and providing recommendations for future research.

2. Methodology

This study employs an inductive approach (Jebreen, 2012) to investigate the challenges faced by SMEs through analysis of multiple secondary sources. The sources of information include scholarly articles, conference papers, theses, government and institutional reports, and websites.

We intend to focus on technical aspects such as: requirement elicitation and management, information management, and risk analysis to support decision making process in SMEs by considering challenges faced in design and development process. The objective is to help SMEs effectively adopt SE by considering their constraints and needs. For comprehensive understanding of challenges faced by SMEs, a study was performed by collecting and critically evaluating the sources of information to identify the most relevant and common challenges. This information is presented in the form of Mind Maps (Davies, 2011). Mind maps present visual information which is processed by humans more efficiently and effectively as compared to knowledge presented in other forms. The collected information is then subjected to an in-depth analysis using critical content analysis to find gaps in existing literature. The analysis results in the synthesis of findings into a reference model (Blessing and Chakrabarti, 2009), that highlights the most important information derived from the sources.

This paper aims to contribute to the literature on SMEs by providing insightful information on the challenges faced by SMEs and making recommendations for future research.

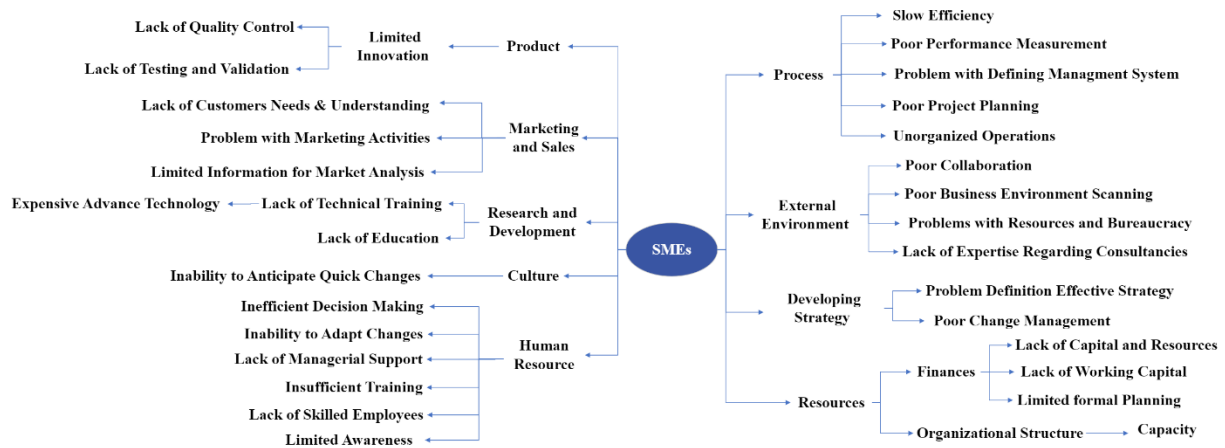
3. Research Background

3.1. Small and Medium Enterprises (SMEs)

SMEs play a key role in a country's economic and societal development. They provide employment, contribute to economic growth, and enhance competition in the market. Furthermore, added value of small and medium enterprises includes innovation, and community development (Bahri, St-Pierre and Sakka, 2011). The importance of SMEs to EU and global economic development along with wealth generation is well known (OECD, 2017).

Along with the added value, SMEs also encounter a range of challenges. These include intensified competition, swift need to adjust with market needs and requirements, increasing technological advancement, and capacity limitations regarding creativity, innovation and knowledge (Chien *et al.*, 2022). Despite the ability, SMEs often fail to achieve their full potential due to the range of factors associated with their small scale. These factors include insufficient resources such as limited finances, access to technology, shortage of skilled and experienced labor. Moreover, these enterprises also suffer from the absence of scale and scope compared to large enterprises and suffer from insufficient networks that can contribute to lack of knowledge and information, know-how and experience related to both national and international markets. The increase in globalization and economic expansion has led to increased market competition and concentration by large industries. Furthermore, SMEs find it challenging to compete with large enterprises in terms of research and development expenditure and innovation regarding organizational processes and products. Lack of entrepreneurial enthusiasm, also presents a significant obstruction to SMEs' ability to achieve full potential (Yoshino, 2016). Figure 1 represents some of these challenges related to SMEs and shows how these may lead to other aspects.

Figure:1 Challenges faced by Small and Medium Enterprises



Source: Representation by authors based on (Tiwari and Buse, 2007; Yoshino, 2016; Alessandrini *et al.*, 2019; Pelletier and Martin Cloutier, 2019; Ghobakhloo *et al.*, 2022)

3.2. Systems Engineering

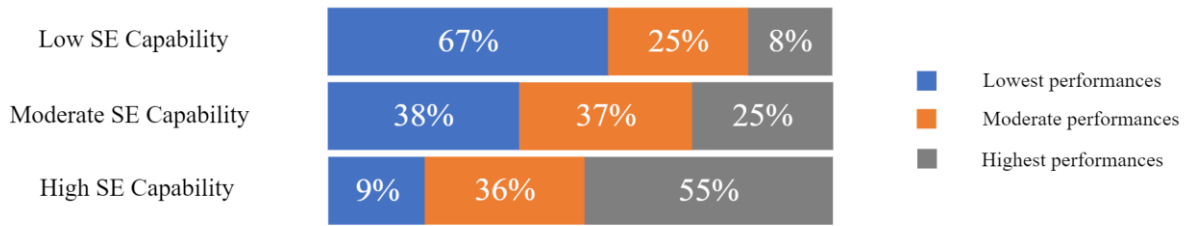
Modern organizations are threatened by a variety of challenges, including increased competition, complexity, limited time to react to changing market dynamics, scarcity of essential and skilled resources, requests for cost reductions, and a constant search for optimization. These challenges can hinder organization's ability to operate effectively and efficiently, as these require significant investment of time, money, and human resources. Therefore, organizations need to formulate strategies to address these challenges to remain competitive and sustainable in the long run. This requires an ongoing commitment to innovation, adaptability, and continuous improvement.

SE is an established field of study, and has been developed to facilitate the successful delivery of projects and systems in complex organizations and environments such as ground control stations, cockpits (Walden *et al.*, 2015). SE deals with technical aspects of system development including design, development, testing and maintenance. It provides a fundamental approach that is closely aligned with project management as it promotes a systematic and structured approach to the development process. SE emphasizes early definition of customers needs and requirements, managing requirements and information, design synthesis, and systems verification and validation. It encompasses the entirety of a systems' lifespan, from conception to retirement with an objective to optimize.

SE facilitates integration among diverse disciplines and specialized groups, leading to a collaborative team effort that establish a structured development process. Moreover, it takes into account business and technical requirements of all the customers and stakeholders with the aim of delivering high quality product that satisfy their needs and specifications (Hall, 2018). SE can be described as “big picture thinking and the application of common sense to projects” through “a structured and auditable approach to identifying requirements, managing interfaces and controlling risks throughout the project life cycle” (Cusk *et al.*, 2009). Systems engineering processes consists of two main objectives, 1) build the right system and 2) build the system right. This refers that SE focuses on the design of a system as specified and verification of the system to ensure that it effectively fulfil specifications and requirements of customers and stakeholders (Boehm, 1984).

Successful application of SE presents considerable positive impact to several segments of the organizations' effort while developing a new system. (Elm and Goldenson, 2014) and (Balslev, 2017) showed that the projects having participants with strong SE knowledge and capabilities are significantly more likely to deliver high level performance. This is achieved by a systematic and iterative approach that involves identifying and analyzing system requirements, designing, and implementing solutions, testing, and validating performance, and system optimization. Figure 2 shows that projects with high SE capabilities achieve highest performance of 55 percent as compared to just 8 percent for project with low SE capabilities.

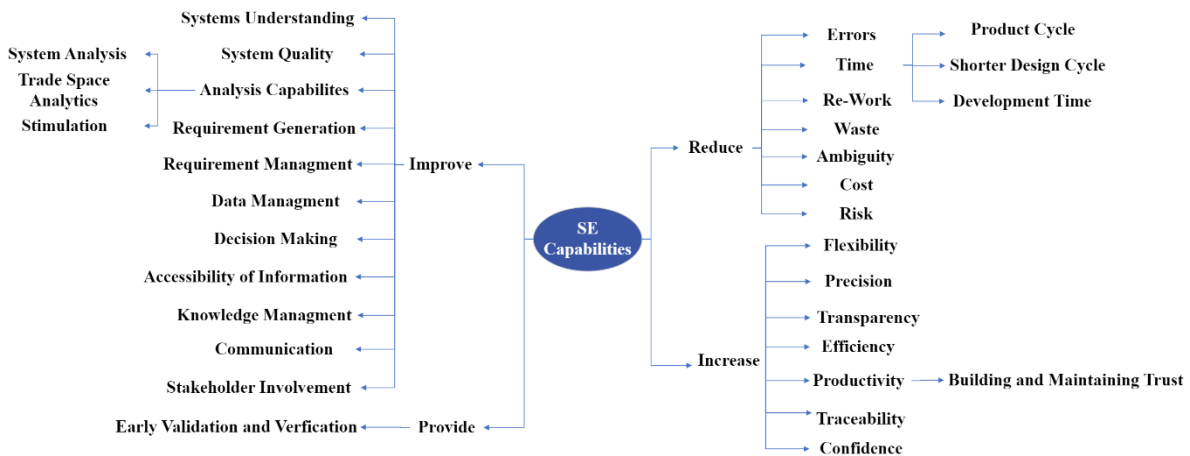
Figure 2: Impact of Systems Engineering Implementation



Source: (Elm and Goldenson, 2014; Balslev, 2017)

Systems engineering capabilities bring a number of benefits and advantages. These capabilities can help to improve organizational abilities, decrease challenges, and increase competencies in SMEs. Figure 3 represents a few SE capabilities that can be beneficial to overcome the challenges faced by SMEs.

Figure 3: Systems Engineering Capabilities



Source: Representation by authors based on (Beasley, 2017; Henderson and Salado, 2021)

Regardless of the widely acknowledged benefits of systems engineering in enhancing complexity management, small and medium-sized organizations (SMEs) have struggled to implement this approach. One of the major reasons for this is the expected significant cost associated with effective systems engineering. Along with this there are other barriers that can affect the adaptation and adoption process in SMEs such as a steep learning curve.

3.3. Adoption (Human Factors) Barriers

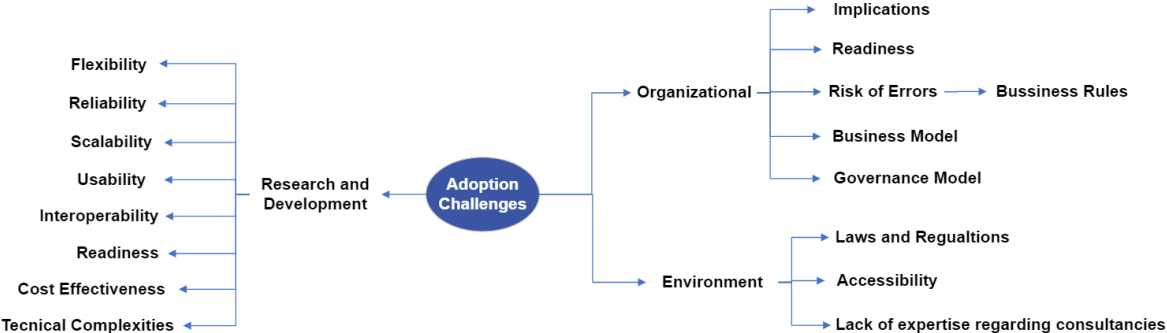
SMEs frequently experience insufficient access to financial and human resources which may hinder their ability to adopt modern technologies or solutions. Implementation of any innovative technology/solution or change in the environment brings a number of concerns for the enterprise and stakeholder involved in the adoption process. A review on organizational study observed over 20 different definitions of adoption and extracted four core characteristics: 1) adoption is generally understood to refer to introduction of a new innovation, 2) distinguish between adoption and invention, 3) adoption is both process and outcome, about a range of activities aimed at incorporating innovation and 4) often requires discontinuous change (Osborne, 1998). According to a study conducted by (Damanpour and Schneider, 2006) various researchers have categorized the innovation adoption process into multiple phases. For instance, (Hage and Aiken, 1967) identified evaluation, initiation, implementation and routinization as the stages of the adoption process. (Klein and Sorra 1996) characterized the adoption process as awareness, selection, adoption and routinization. (Zaltman *et al.*, 1973) described the adoption stages as knowledge awareness, attitude formation, decision, initial

implementation, and sustained implementation. Furthermore, study conducted by (Van de Ven *et al.*, 2000) distinguished adoption process into four stages including initiation, development, implementation and termination. Systems engineering involves a wide range of tools, techniques, processes, practices, and actions, which can be daunting for organizations with limited resources (Kossiakoff *et al.*, 2020). Furthermore, it requires a steep learning curve which can affect the adoption at SMEs.

There are several challenges to be considered while introducing a new way of working, especially if this requires changing the working environment. Most prominent challenges are environmental, technological, and organizational. Technological challenges are cited as the most significant barrier to the technology adoption at SMEs (Ghobakhloo *et al.*, 2022). Figure 4 presents a few adoption barriers that may hinder SE adoption process.

These challenges focus on the following human factors that are considered significant in research on information systems and technology. 1) perceived relative advantage of the innovation, 2) personal beliefs and values about technology, 3) perceived complexity, 4) previous experiences, 5) exposure to the technology, 6) attitude towards change and 7) communication behavior. Individual acceptance and rejections are based on these factors (Nedovic-Budic and Godschalk, 1996).

Figure 4: Adoption Hindrance in Small and Medium Enterprises



Source: Representation by authors based on (Del Aguila-Obra and Padilla-Meléndez, 2006; Khan and Qudrat-Ullah, 2021; Ghobakhloo *et al.*, 2022)

4. Discussion

In this work we present the challenges that may appear at SMEs at various levels and phases of the product or systems life cycle. To demonstrate this, we used the mind map technique (Guerrero and Ramos, 2015), that helps to visualize relations among various aspect of a factor. This way, the objectives of the study can be seen better. The perspectives presented here are derived from researchers’ viewpoint based on analysis of existing literature and identification of gaps within the problem and solution domains. Figure 5 shows the concept map related to impact of SE introduction to the challenges faced by SMEs and why SE support needs adoption perspective in this context.

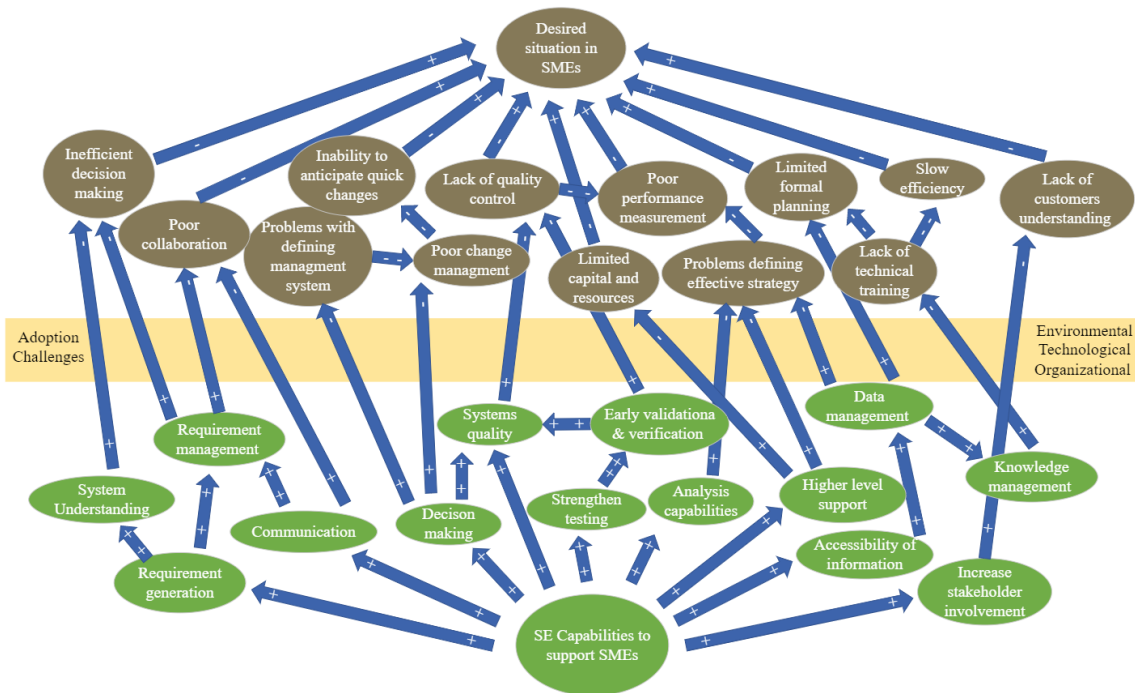
For better understanding of the situation and working conditions related to SMEs, literature exploration was done, and the extracted information shows the challenges that are faced by these enterprises and how these challenges are impacting the working environment of SMEs. Figure 1 presents these challenges and categorized into different sections such as challenges faced by external environment factors, research and development, related to product and organizational processes etc. For example, *resources*: due to limited finances of SMEs has less capital which has a negative effect on the working capital, and this leads to the scarcity of skilled employees. This affects the decisions capability in organization or on-going project. SMEs are not the only businesses who faces this problem, some of these problems are common in large industries as well. Due to limited resources and other constraints, these challenges are becoming more prominent and require a systematic solution to the problem as failure of one project can be fatal in context of SMEs.

Systems engineering is employed by large industries to manage complexities and we propose to introduce it in SMEs to overcome the challenges faced by them. Figure 3 presents some of the

capabilities that may be helpful to overcome the challenges appearing in these enterprises. To demonstrate a potential impact of SE solution, we select a challenge from SMEs for instance *poor performance measurement*. SE capabilities offer enhanced testing protocol that enables early validation and verification during product life cycle. Similarly, with the dominos effect of same problem, if a firm faces a challenge regarding increase in poor performance that may lead to problems with quality control, SE offers better product quality and better analysis capabilities to maintain good product quality.

The review of literature reveals that systems engineering implementation can provide SMEs with numerous benefits. Regardless of the evident benefits SE can offer to SMEs, there are only a few examples where SMEs are adopting SE. Authors believe that the steep learning curve of SE at very initial phases and expected high investment are some of the few factors that make it difficult.

Figure 5: Impact of Systems Engineering to SMEs Challenges



Source: Authors own representation

This study took into consideration the limitations of SMEs and looked at this problem from a different perspective. We proposed to include the adopters (human at SMEs) perspective to the problem definition and potential solution support that may lower the adoption learning curve and minimize the initial investment cost as given by (Honour, 2010). Studies mentioned in adoption challenges highlight several adoption challenges regarding new technologies and innovations that can hinder the SE implementation in the working environment. These challenges are divided into three categories, see figure 4, those may need to be considered while introducing solution support by considering problem domain. Figure 5 represents a concept map that will be used as reference model. This was developed on the basis of most important challenges and the reflection of SE capabilities to minimize SMEs challenges. The model also refers towards the adoption challenges as noise which may present as hurdles in SE adoption process. This study proposes a further investigation to design a support to overcome SMEs contemporary situations, by considering the adoption perspective related to human aspect in both problem and solution domain.

5. Conclusion & Future Work

This study brings insights on the challenges faced by SMEs and presents systems engineering as a potential solution to overcome these obstacles. We presented the potential benefits from literature towards SE introduction in SMEs. A further investigation was conducted to explore potential hindrances to the possible solution in this context. Three mind maps were developed for each aspect: SMEs challenges, SE capabilities and adoption challenges. These mind maps converge into a concept map that highlights the impact of potential solution and shows how SE adoption may have promising influence on SMEs working environment. It shows that systems engineering adoption in SMEs impact positively and will help to overcome number of challenges including requirement and knowledge management, and testing and validation related to design and development processes.

The study presents certain limitations, it is based on secondary sources and shows our position in this regard. Future work will present how SMEs potentially see systems engineering as a solution to their problems and hurdles. We will evaluate the findings from SMEs to cover both perspectives; systems engineering as a solution and to overcome adoption challenges from human factors context. Our goal is to complete the first task and develop support to introduce systems engineering. SMEs from different technical capabilities (such as electronic and medical device development and food processing) will be recruited to evaluate the results on a broad range of enterprises.

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