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Incorporating Systems Engineering into Project Management Enhances Operational Efficiency

Simona Huguet[1], Petra Bláhová[1], Radka Procházková[2], Jan Saro[1], Helena Brožová[1]

[1] Department of Systems Engineering, Faculty of Economics and Management, Czech University of Life Sciences Prague, Czech Republic

[2] Department of Statistics, Faculty of Economics and Management, Czech University of Life Sciences Prague, Czech Republic

Abstract

Project management (PM) orchestrates multiple processes and resources while ensuring compliance with quality standards. But as projects become increasingly complex, lifecycle PM struggles to optimize risk mitigation strategies. Nevertheless, Systems Engineering (SE) may complement PM in managing complex projects and mitigating associated risks. Testing this hypothesis, this study assesses whether integrating SE into PM improves project execution. Our qualitative research and data analysis highlight the adaptability of SE in addressing intricate issues. Moreover, our findings demonstrate that incorporating SE into PM methodologies substantially improves the execution of complex projects.

Keywords

Collaboration, project, project management, project manager, systems engineer.

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Introduction

Three key factors, namely time, cost, and quality, determine the outcome of a project. In project management (PM), these three boundaries form an equilateral triangle, setting the limits of the project and collectively defining its scope based on the best ratio of these elements (Radujković and Sjekavica, 2017). Any deviation from this equilateral triangle entails a deviation from optimal PM and jeopardizes the success of a project.

A project is an activity with a defined beginning and end, so it does not repeat. By contrast, processes within a project can be repeated and remain consistent (Leong et al., 2014).

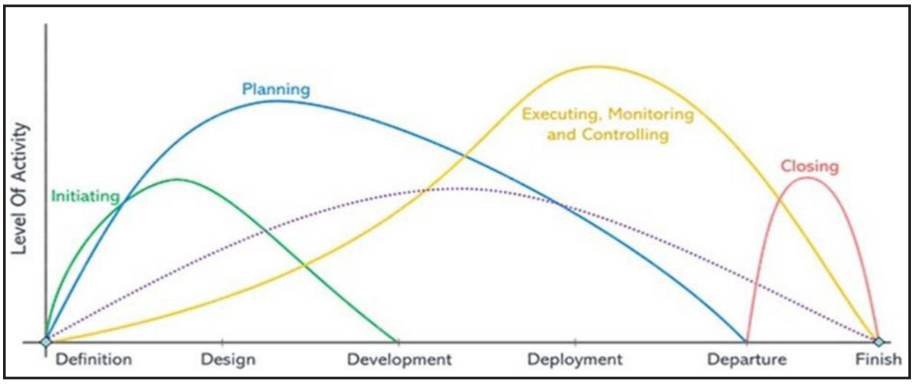
Accordingly, PM adds value to an organization, proving essential to the growth and development of modern industry (Galli, 2020b).

PM success has long been studied in both scientific and practitioner literature (Varajão et al., 2022). The better PM processes are, the most likely a project will be completed with high quality (Schoper et al., 2017). But improving PM requires reacting to every opportunity and overcoming challenges. Unlike processes and operations, projects are unique and must be addressed individually (Learning, Kerzner and Belack, 2010), considering both shared and specific characteristics of human, material, and mixed resources in leading a project (Wagner, 2019). As a time-bound and comprehensive set of activities and processes aimed at introducing, creating, or changing something specific, a project must be managed differentiating individual tasks from major activities encompassing many processes (Project Management Institute, 2008).

As projects become increasingly complex (Müller and Turner, 2007), lifecycle-focused PM struggles to manage associated risks (Mabelo and Sunjka, 2017). Nevertheless, applying systems engineering (SE) concepts can improve the management of complex projects and risk mitigation (Iriarte and Bayona, 2021). Because SE processes are adaptable, they are suitable for managing complex problems (Galli, 2020a).

Project lifecycle

Completing a project requires appropriate PM, which can also help to reduce risks in project processes. Increasing control over processes increases the probability that a project will be completed on time (Alzoubi, 2022). The full life cycle of a project is described in Figure 1. All



Source: Chand (2024)

Figure 1: Project management life cycle.

stages (Initiating, Planning, Executing, Monitoring and Controlling, and Closing) can be streamlined by improving PM skills and competitions (Level of Activity).

Figure 1 illustrates the role of project managers across various project phases. Initially, project managers define the project and set objectives. Planning involves a detailed scope, schedule, and resource management. During execution, they implement the plan, monitor performance, and manage changes (Sima, 2022). In closing, they ensure deliverable acceptance and complete documentation. Key skills include leadership, communication, and adaptability (Halushka, 2021).

As outlined in Table 1, increased rates of project failure commonly derive from cost and time overruns (Bilir and Yafez, 2022) and from the lack of consistency between tasks and/or the whole project because current PM practices increasingly fail to manage risks (Hilson, 2014). At the core of these notable deficiencies lies the inability to manage increased complexity.

Effectively mitigating risks associated with increasingly larger and more complex projects requires a new approach to PM (Cristóbal et al., 2018). The systems approach has the potential to improve PM and its practices (Galli, 2020a).

Sector	No. of projects	Cost Overrun (%)	Time Overrun (%)
Atomic energy	12	25	91.67
Civil aviation	47	42.52	91.49
Coal	95	22.11	61.05
Fertilizers	16	25	62.5
Finance	1	100	100
Health and family welfare	2	100	100
I&B	7	42.86	100
Mines	5	0	80
Petrochemicals	3	33.33	100
Petroleum	123	20.33	79.67
Power	107	46.73	60.75
Railways	122	82.79	98.36
Road transport and highways	157	54.14	85.35
Shipping and ports	61	31.15	95.08
Steel	43	18.6	81.4
Telecommunication	69	15.94	91.3
Urban development	24	41.67	100

Source: Singh (2009)

Table 1: Cost and time overruns in infrastructure projects by sector - An enquiry into extents. Causes and Remedies.

The integral role of the systems engineer across the project life cycle

The ('Systems Engineering Guidebook', 2022) defines a system engineer as a professional who applies a systematic, interdisciplinary approach to "designing, integrating, and managing complex systems over their life cycles". This role involves coordinating various engineering teams, ensuring that all system components work harmoniously, and meeting requirements and performance standards. The system engineer focuses on the holistic functionality of a system, encompassing its development, operation, maintenance, and eventual decommissioning (Oehmen et al., 2012), while addressing both technical and managerial aspects.

Several studies have already addressed the relationship between the systems engineer and the project manager towards improving processes and, thus, successfully completing the whole project (see Table 2). These studies have delved into inherent risks, risk mitigation strategies, and the scale of various projects. Yet, despite their extensive analysis, no study has comprehensively examined the role of the systems engineer throughout the project life cycle and its distinct phases.

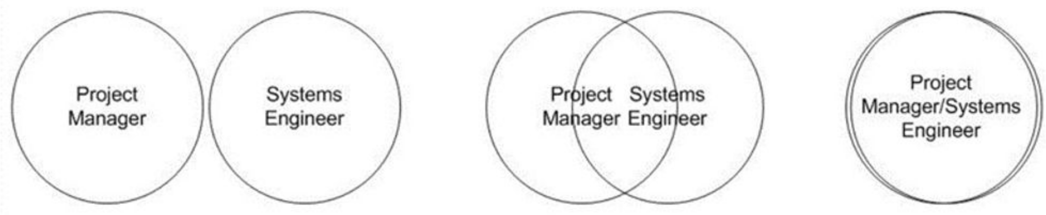
R. Turner, A. Squires	Relationships between Systems Engineering and Project Management	2024
Brian J. Galli	The Application of Systems Engineering to Project Management A Review of Their Relationship	2020
João Varajão, António Trigo, José Luís Pereira, Isabel Moura	Information systems project management success	2021
	Guide tom the Systems Engineering Body of Knowledge v2.10.	2018
João Varajão	The many facets of information systems (+projects) success	2018

Source: Authors

Table 2: Technical articles and other publications focusing on project improvement through a systems engineer (2024).

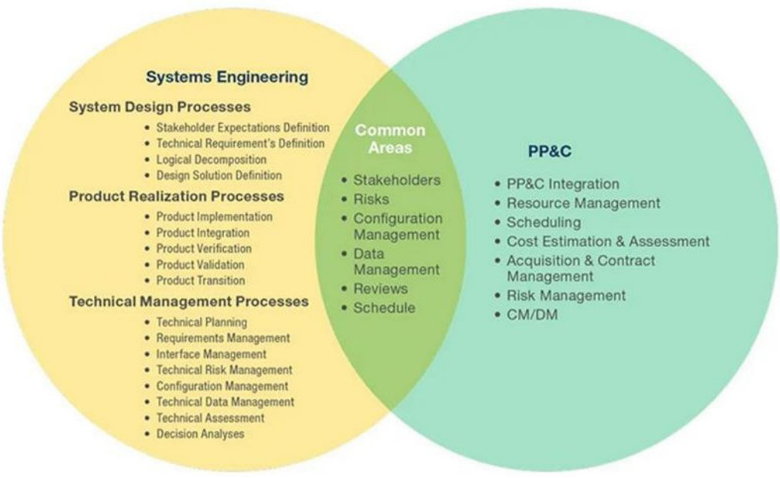
Systems engineers can help to ease the workload of project managers, enabling them to focus on more sophisticated tasks, such are setting project targets (Munns and Bjeirmi, 1996), managing resources and budgets, and communicating with sponsors and stakeholders ('NASA Systems Engineering Handbook', 2007). Systems engineers can also tackle more technical aspects of the project, including system design, development, and maintenance, project planning and monitoring, and risk confrontation (Turner and Squires, 2024). Thanks to this technical support, project managers have more time to focus on activities of the overall project and on project sponsors (Kordova, Katz and Frank, 2018). As shown in Figure 2, these functions are interrelated, overlapping to some extent.

SE is essential in project organization, particularly in three main tasks: managing technical aspects, overseeing the project team, and controlling costs and schedules. SE makes technical, cost, and schedule decisions, providing this information to PM. In turn, Project Planning and Control (PP&C) manages project costs and schedules (*SEH 2.0 Fundamentals of Systems Engineering - NASA*, no date), ensuring that the project delivers a technically sound system within budgetary and time constraints. SE and PP&C partly overlap, but SE provides technical inputs, while PP&C offers programmatic, cost, and schedule inputs (Figure 3)..



Source: Turner and Squires (2024)

Figure 2: Overlap between project roles.



Source: SEH 2.0 Fundamentals of Systems Engineering - NASA (2019)

Figure 3: Systems Engineering in Context of Overall Project Management.

Materials and methods

Collaboration between systems engineers and project managers

The present study employed a qualitative research design aimed at achieving analytical rather than statistical generalization typical of quantitative research. While statistical generalization seeks to draw inferences about a population based on empirical data from a sample, analytical generalization requires comparing empirical case study results with pre-existing theoretical frameworks. This study predominantly relied on semi-structured interviews with project managers.

The interviewees were project managers, each of whom leading teams of 10-15 members. These managers were employed by corporations in the Czech Republic, each of which with a workforce exceeding 250 employees. The sample comprised 10 seasoned project managers recognized as subject matter experts in their respective domains. These individuals were selected based on their professional standing, educational background, and extensive experience, which collectively underscored their expertise in the field (Figure 4).

The following measures were implemented to ensure the trustworthiness (internal validity) of the qualitative findings:

Triangulation: A finding was deemed trustworthy and valid if mentioned in at least three interviews. This qualitative study based on semi-structured interviews precluded statistical analysis, typical of quantitative studies. The convergence of similar topics across three different interviewees served as a triangulation procedure to enhance the internal validity of the study.

Cross-validation: Throughout the interview process, cross-validation was performed to assess the consistency of respondents' agreement with the provided definitions (respondent validation).

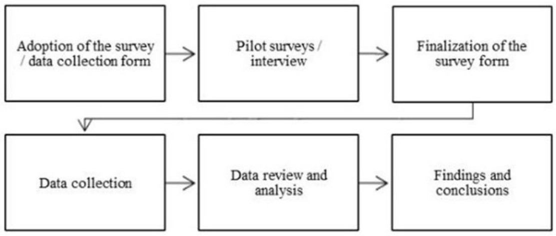
To ensure confirmability, the extent of objectivity was consistently examined throughout the research process using the following techniques:

Unbiased Questioning: The interview questions were carefully crafted to ensure that they were clear and unbiased, so that the responses were not influenced by the wording.

Error minimization: Measures were implemented to minimize errors stemming from initial impressions and early assumptions, thereby enhancing the generalizability of the research findings to the broader population (external validity—fittingness).

The research sampling procedure was also carefully designed to avoid bias towards either PM or SE. An equal number of participants from both domains were interviewed to ensure balanced representation.

Highly regarded experts from the PM community were selected based on their recognized expertise and contributions to the field.

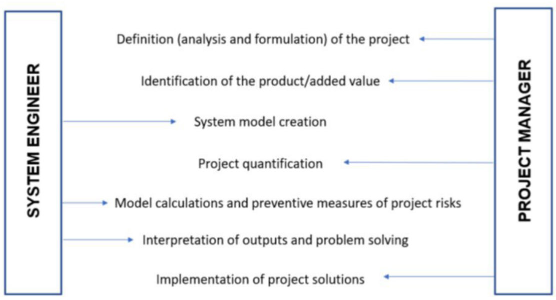


Source: Authors

Figure 4: Study methodology.

Results and discussion

SE combines elements from many areas: operations research, systems modelling, specification writing, risk management, requirements development and PM. PM is all about achieving practical results, completing tasks and repairing things. When working on a large and complex project or on a project requiring a deep technical background, collaborating with a system engineer may prove particularly helpful, even more so if the project manager lacks technical skills. Project managers and system engineers can bridge gaps on the life cycle of a project and work together harmoniously until its completion. To this end, both of them must feel that they are equal partners, collaborating to meet all stakeholders' expectations (Figure 5).



Source: Authors

Figure 5: Collaboration between systems engineer and project manager.

Nearly 90% respondents stated that they already leveraged the expertise of systems engineers during the implementation or coordination phases of projects, with unanimous agreement on their efficacy and contribution to successful project completion. Depending on the project life cycle, which is divided into distinct phases, 45% project managers agreed with the assertion that a systems engineer should be included in the team from inception to conclusion. Additionally, 90% respondents believe that the systems engineer should be primarily involved in the project during the Management and Coordination, and Monitoring and Controlling phases. A slightly lower percentage (78%) highlighted the importance of the systems engineer's engagement across all phases — Initiating, Planning, Management and Coordination, Monitoring and Controlling — excluding only the Closing phase. Figure 6 shows the percentage of weights assigned to each phase of the project cycle, indicating the level of involvement required from the system engineer in each specific phase.

The role and significance of a systems engineer in project development greatly depends on the size and type of project. In smaller projects, project managers and senior technical staff often take on the responsibilities of a systems engineer, rendering the role less critical. However, in larger projects, the role of a systems engineer becomes indispensable, sometimes requiring an entire department. The need for systems engineers also varies with the type of project — technical projects, such as manufacturing, heavily rely on systems engineers, while their involvement in case studies or purely financial projects may be minimal. Overall, systems engineers are crucial for minimizing errors, providing clear structure, and enhancing project efficiency, tailoring their involvement to the specific requirements of each project.

Considering the above, the respondents had the opportunity to express their judgment in text. Respondents assigned weights ranging from 1 to 10 to each task activity (Figure 7), reflecting the perceived importance of the systems engineer's role within a project. These weights serve as indicators of the significance attributed to each task, demonstrating the critical influence of SE on the overall success of a project.

Through close collaboration between project managers and systems engineers, organizations can effectively manage project risks and identify potential roadblocks before they impact the project. An integrated approach to PM requires organizations to clearly understand the project scope, objectives, and stakeholders. This understanding should be

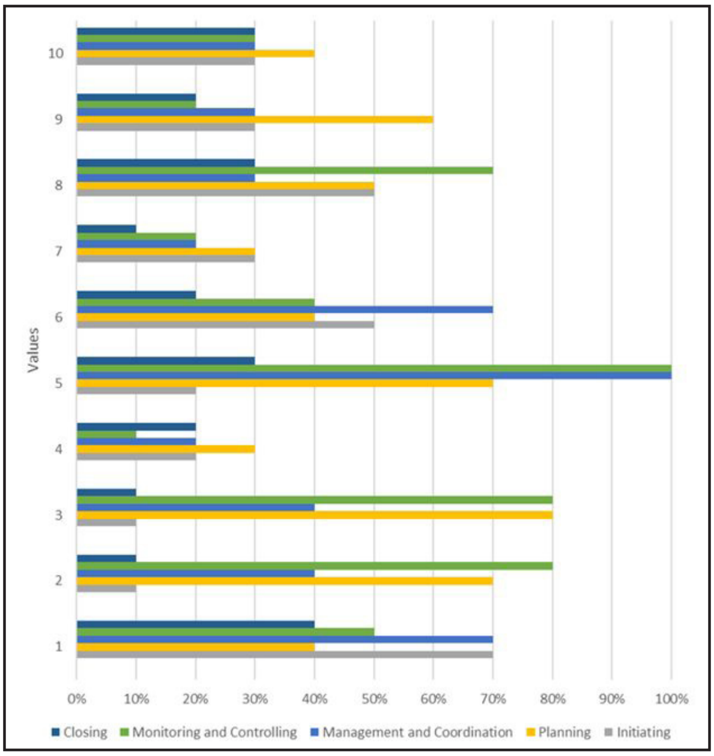


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Figure 6: Respondents' answers by phase of the life cycle of a project.

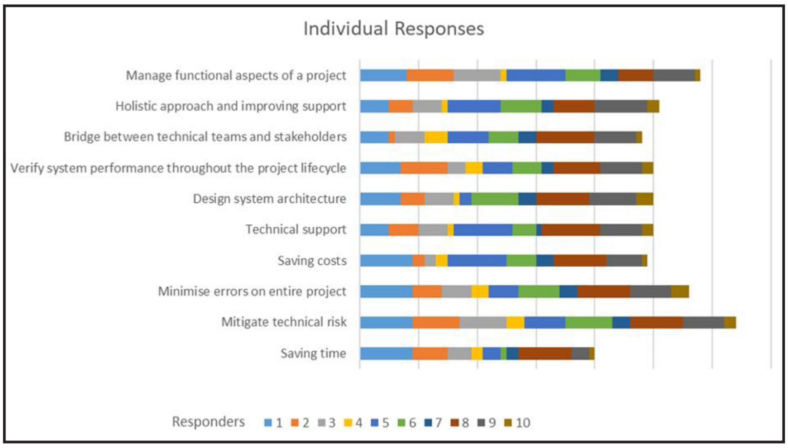

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Figure 7: Individual responses.

communicated to all stakeholders and recorded in project documentation. An integrated approach to PM, especially in managing stakeholders' demands, yields successful risk mitigation and project coordination. The results below synthesize responses of the experienced project managers.

The main collaboration steps are:

1. Definition (analysis and formulation) of the project
2. Identification of the product/added value
3. System model creation
4. Project quantification
5. Project review
6. Interpretation of outputs and problem solving
7. Project completion

1. Definition (analysis and formulation) of a project

For successful PM, the new product of a project must be clearly defined, providing a clear focus for the entire process. This initial definition should guide PM efforts, keeping the project aligned with its objectives and on track. Therefore, the first step of the PM process is to clearly and concisely define the new product, including its goals, objectives, and scope upon consensus among all stakeholders for a common understanding of the purpose of the project.

A significant challenge arises when a project manager is unable to accurately define the individual steps of a complex project, particularly in an unfamiliar domain. Mitigating this risk requires involving a systems engineer from the inception of the project. This collaboration ensures that no essential questions are overlooked and that all queries are addressed precisely, correctly, and promptly. The systems engineer's involvement also reduces human error during project implementation by providing clear, detailed information to each team member about their specific tasks and priorities.

Engaging a systems engineer facilitates productive discussions with the project sponsor, allowing professional inquiries about systems aspects of the project, the proposed product and its requirements and expectations. This approach not only strengthens product specifications but also saves time and reduces overall project costs. Prolonged projects tend to be more expensive and erode client confidence in the project manager's capabilities. Therefore, early and continued collaboration between the project manager and the systems engineer promotes sustained project efficiency, cost-effectiveness, and stakeholder trust.

2. Identification of the product/ added value

In the subsequent step, a comprehensive and detailed project plan is tailored to the specific project. This plan should encompass the timeline, tasks, resources, and budget necessary for project completion. With input from the systems engineer, the project manager addresses areas requiring additional expertise or guidance. Tasked with articulating expectations and providing a detailed description of the new product or service, the project manager assumes a greater responsibility than the systems engineer during this step. The systems engineer's role consists of providing professional insights and sharing comments to support the project manager's decisions and to ensure technical accuracy.

3. System model creation

In the third step, the project plan is executed, which involves task assignment, resource management, and progress monitoring. The project manager is responsible for ensuring that all tasks are completed on time and within the allocated budget. Recent advances in AI tools and supports offers opportunities to accelerate processes, to simplify tasks, and to reduce human errors. However, given the breadth of these advancements, a project manager cannot comprehensively master all new programs and tools essential for informed decision-making. Consequently, project managers often rely on their existing practical experience, which is insufficient on its own, so an organized framework must be established to integrate these new tools and methodologies systematically.

4. Project quantification

Properly planning the budget is essential to meet project timelines, to control costs and to achieve the expected results. Key questions every project sponsor wants answered include: How long will it take to prepare and complete the project? What is the total cost, and does it fit within the set budget? How will the financial aspects of pilot implementation or gradual sector development within the company's existing system differ? Will the budget or implementation time be exceeded?

Addressing these questions, the project manager initiates the planning process, leveraging their skills in team leadership, motivation, and task estimation based on past projects.

However, there is a significant risk of deviation in judgment without comprehensive analysis and support. A systems engineer can provide professional advice, offering different perspectives when necessary. This collaborative approach fosters more precise calculations and helps mitigate the risks of delays and unforeseen costs. The systems engineer's input ensures a detailed evaluation of technical requirements and potential issues, enhancing the accuracy of budget and timeline estimations, thus ensuring the project's success.

5. Project review

The fifth step is to review the project, a critical phase in the PM process that allows the project manager to assess progress, identify issues, and make necessary adjustments.

Leveraging the systematic perspective of a systems engineer highly skilled in IT systems can be particularly beneficial at this stage. The systems engineer's education and experience enable the project manager to identify and mitigate risks effectively. Additionally, the systems engineer can introduce preventive measures and other relevant solutions, further enhancing the project's success and stability. This collaborative review ensures that all aspects of the project are thoroughly evaluated, leading to informed decisions and continuous improvement.

6. Interpretation of outputs and problem solving

Each project is unique, and while a project manager can prepare for anticipated problems, unexpected issues may cause additional costs and delays. A systems engineer must be engaged in the project from its inception to address unforeseen challenges proactively. The systems engineer's expertise can help to identify potential risks and implement preventive measures early on, thereby facilitating progress in subsequent phases of the project. This collaborative approach enhances the project manager's ability to interpret outputs accurately and to resolve issues efficiently. As a result, the project stays on track and within budget.

7. Project completion

The final stage of the project involves introducing solutions, relying on the collaboration between the project manager and the systems engineer. Based on high-quality skills and mutual trust, this partnership ensures adherence to timelines and budgets while maximizing client satisfaction. The project manager leads the effort, supported by the systems engineer's professional advice in addressing technical challenges. Investing in a systems engineer from the beginning and throughout the project helps to pre-empt issues, ensuring smooth progress.

In this stage, the focus is on confirming that all deliverables meet quality standards and client expectations. With the systems engineer's support, the project manager conducts the final testing, user training, and formal handover of deliverables. Ensuring a seamless transition and providing the necessary post-implementation support sets the project on a path towards success and fosters client trust.

Conclusion

The integration of Systems Engineering (SE) into Project Management (PM) practices has demonstrated considerable potential in enhancing operational efficiency, improving project outcomes, and mitigating risks, particularly in complex project environments. This study has explored the complementary roles of project managers and systems engineers, highlighting the critical intersections where collaboration between these professionals' results in greater project success.

By adopting a systems approach, project managers are better equipped to handle the growing complexity and scope of modern projects. Systems engineers contribute significantly to technical decision-making, risk assessment, and problem-solving, while project managers focus on achieving strategic objectives, stakeholder communication, and overall project coordination. This partnership allows for a more balanced distribution of responsibilities, ensuring that technical and managerial aspects are equally addressed throughout the project lifecycle.

The empirical findings from this study confirm that the active involvement of systems engineers —particularly in the initiation, planning, and monitoring phases—has a direct and positive impact on project efficiency, cost control, and timely delivery. The ability of SE to provide systematic analysis, anticipate potential risks, and implement structured processes has proven invaluable in supporting project managers and fostering a collaborative environment focused on project success.

Moreover, the study underscores the importance of early and continuous integration of SE into PM practices. Early engagement of systems engineers helps to clarify project objectives, refine system requirements, and establish realistic budgets and schedules. Continuous collaboration throughout the project lifecycle further ensures adaptability and responsiveness to emerging challenges, reducing the likelihood of costly delays or quality compromises.

Despite these positive outcomes, the research also acknowledges the need for more standardized frameworks and methodologies that facilitate effective collaboration between project managers and systems engineers. Future research should focus on developing integrated models that clearly delineate roles, responsibilities, and decision-making processes. Additionally, further studies could explore the impact of SE integration in different industry sectors and project types, including those less reliant on technical systems, to assess the universality and scalability of the approach.

In conclusion, this study highlights the significant value of incorporating Systems Engineering into Project Management. As projects continue to increase in complexity and stakeholder expectations grow, fostering interdisciplinary collaboration will be essential for achieving sustainable project success. Organizations that recognize and support this integrated approach are more likely to deliver high-quality, timely, and cost-effective outcomes that meet or exceed stakeholder expectations.

SE should be incorporated into projects to enhance operational efficiency and support PM. These findings open up opportunities for further research, highlighting the integral role of SE in successful project execution.

Corresponding author:
Ing. Simona Huguet
Department of Systems Engineering, Faculty of Economics and Management
Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague - Suchdol, Czech Republic
E-mail: huguet@pef.czu.cz

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