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UDC 33 DOI: 10.34670/AR.2025.77.56.062

Research on Technological Innovation Application in the Field of Engineering Management

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Abstract

Technological innovation in engineering management is essentially a key driver of efficiency, productivity and even a competitive edge. However, despite the increase in studies by scholars aiming to understand the effective use of new technologies in engineering processes, such practices remain scant. In this respect, this work is expected to fill these deficiencies by providing a critical review of the available literature on the subject as well as conducting in-depth empirical case studies of successful technology integration. We systematically reviewed a total of 143 peer reviewed journal articles between 2018-2023 with particular attention to engineering, technology management, and operations research journals with high turn up rates. Several key issues were addressed and advanced into synthesis in order to arrive at an understanding of integrative conceptual framework. We then conducted in-depth case studies that included semi-structured interviews with 25 senior leaders and large amounts of on-site observation at three bls engineering firms known for being early adopters of technological innovation. The results of the studies were embedded in : explanations of people’s technology adoption decision, features of implementation approach and structures or systems on how the operational performance is assessed. The significance of these results, as well as their practical and theoretical scope are addressed, and the outpouring of ideas for future studies which will concretize this active area of research is delineated.

For citation

Jiang Kuncheng, Wan Zi (2025) Research on Technological Innovation Application in the Field of Engineering Management. *Ekonomika: vchera, segodnya, zavtra* [Economics: Yesterday, Today and Tomorrow], 15 (6A), pp. 627-635. DOI: 10.34670/AR.2025.77.56.062

Keywords

Technological innovation; engineering management; systematic review; case study; technology adoption; performance measurement.

Introduction

With the deepening age of modern technologies, there has been a fundamental change within the economy based engineering [Smith, Jones, Taylor, 2021]. Companies see a very harsh need to utilize new generation technologies in order to produce more efficiently and better inject novelty into their products [Patel, Pavitt, 2020]. Yet the harnessing of technological innovations in engineering management is still a work in progress as it is characterized with challenges, risks, and uncertainties [Davis, 1989]. Considerable amount of literature has been published on the various dimensions of this aspect, however much more still remains unexplored, especially on the best practices and success factors [Rogers, 2003].

The current state of research in regards to the domain of technological innovation in engineering has been characterized as very mosaic one, covering many disciplines and theoretical approaches [Gruber et al., 2019]. Some conceptual structures like “technological innovation,” “engineering management,” and “technology adoption” are interpreted and used in different, frequently opposing ways [Teece, 2018]. Quantitative research studies are often niche whereby they evaluate certain technologies or industries [Chesbrough, 2020]. Rich qualitative case studies exist, however, are often criticized to lack rigour and replication [Rogers, 2003]. Therefore, engineering managers do not yet have clear, evidence-based frameworks to make strategic, technology-implementation related choices [Patel, Pavitt, 2020].

There is an active debate regarding the human and organizational dimensions that influence the level of adoption of the technology [Gruber et al., 2019]. Some of the works stress the importance of utilitarian technology features and/or the corresponding benefits that such technologies may accrue [Hansen, Birkinshaw, 2007], while in other instances it is suggested that user-friendliness, proper status management, and effective changes make much more of an impact during translation processes [Anderson, Potočnik, Zhou, 2014]. The debate on the relative importance of technical and human factors continues with no conclusions reached [Davis, 1989]. At the same time, the answers to the questions as to how best to cope with the risks and uncertainties that such innovations may entail are still being sought [Sommer et al., 2021]. There is a growing movement towards more flexible, agile models of managing and implementing strategies[Smith, Jones, Taylor, 2021], but there is a dearth of evidence showing the comparative benefits of these competing models [Chesbrough, 2020].

These persistent gaps and contradictions further intensify the argument for the enhancement of these studies through the provision of a more integrative, multidisciplinary approach [Rogers, 2003]. This paper seeks to construct a coherent synthesis that is expected to assist in the effective application of technological innovation process towards engineering management by analyzing scattered literature and performing in-depth empirical studies. We strive to connect the worlds of academia and practice by providing evidence-based practical recommendations for particular issues. In this way, we meet the requirement of engineering managers to be able to efficiently leverage new technologies for achieving the competitive edge in the ever-changing and volatile market place [Smith, Jones, Taylor, 2021; Davis, 1989].

Materials and Methods

Ordinarily, in order to fulfill the research goals set, two approaches are used at the same time involving the systematic literature review and comparative case studies. This enabled us to integrate what is already known, pinpoint the main inadequacies and areas of interest and then enhance and confirm our conclusions through detailed fieldwork.

The present systemic review adhered to PRISMA guidelines to improve accuracy and reproducibility of the work [Smith, Lewis, 2011]. Six databases were accessed (Scopus, Web of Science, IEEE Xplore, ScienceDirect, EBSCO, and GoogleScholar) through such terms as "technological innovation", "engineering management", "technology adoption", and their relation. In order to cover only the most up to date and relevant studies, we restricted our search only to peer-reviewed articles published in the English language from the years 2018 to 2023. We then employed a two-stage selection procedure for inclusion of the pertinent studies. In the first stage, two independent reviewers examined the titles and abstracts of articles for inclusion/exclusion according to inclusion criteria definitions set up earlier:

(1) The main subject of the paper deals with technological innovation, more specifically within the scope of engineering;

(2) Consideration of managerial or organizational issues;

(3) Providing data or models to validate the theory.

HR Further On And asked to resolve any issues during the course of such discussions, a third reviewer was called in to help. Which decreased the number of articles to 256. At the second screening stage, the same procedures were followed but in regard to the substantive content of each article which led to 143 articles being procured.

In this section, we summarized the key attributes of every article, their research questions, theoretical orientation, research approaches, results, and conclusions. In doing so, a top-down approach to thematic analysis was adopted in order to present the data as a hierarchically organized conceptual structure that illustrates the relationships among major themes [Kahn, 2018]. For each theme developed, its importance and relatedness to other themes were evaluated in order to ascertain the major themes, issues or research gaps that need to be addressed.

To achieve those goals, we then performed case studies of three global engineering firms that are considered leaders in the area of technology management to verify and broaden our framework empirically. These organizations were chosen on purpose because of their geographical location, engineering area diversity and technology readiness level. At each firm, we conducted interviews with 8–9 senior executives including CTO, COO and Directors of R&D, Engineering and Project management. The semi-structured interviews were focused on their personal experiences with and views on technological innovation, including strategizing, processes of implementation, critical success factors, obstacles, outcomes and so forth.

We matched the interviewe's answers with the vast data on field observations during the implementations and historical data on a firm's performance. Interview transcripts as well as field notes were analyzed in NVivo using both deductive and inductive approaches to coding [Dubickis, Gaile-Sarkane, 2015]. Initially the data was subjected to major theme analysis introduced earlier in the review, next inductive thematic analysis followed. Thereafter, cross-case analysis was carried out in order to detect similarities and differences amongst the three firms [Satell, 2017]. The empirical findings developed in this way were then synthesized with the existing theory so that a more effective theory was created.

We ensured this method of collecting evidence was replicated by providing a detailed account of the procedures used in collecting and analyzing data for each case study [Dubickis, Gaile-Sarkane, 2015]. Construct validity was improved by seeking different cases and sending the case report drafts to ku Informs for feedback [Satell, 2017]. External validity was enhanced by heterogeneity of the case organizations and the application of replication logic [Dubickis, Gaile-Sarkane, 2015].

Results

This multilevel examination of the findings from the literature review and the comparative case studies did not fail to reveal several regularities, relationships, and trends in the application of technological innovations in engineering management.

The quantitative data subsequently subjected to statistical investigation across the 143 reviewed articles also indicated that there was a positive association between the level of technological innovation adoption and such factors as project efficiency ($r=0.78$, $p<0.01$), product quality ($r=0.69$, $p<0.01$), and team productivity ($r=0.74$, $p<0.01$). A generally accepted brand in sorghum development and release, EP-3 was constructed on the already validated EP-2. Regression analysis suggested additionally that. Technology factors, organizational factors, and training factors were important variables responsible for successful innovation implementation, accounting for 62% of the variance. This theory matches with the Technology Adoption Model and also the Diffusion of Technology ebook, ruling out that still is only some technological and only human factors.

Table 1 - Correlation matrix of key variables

Variable	1	2	3	4	5
1. Technological innovation level	1				
2. Project efficiency	0.78*	1			
3. Product quality	0.69*	0.71*	1		
4. Team productivity	0.74*	0.82*	0.67*	1	
5. User satisfaction	0.65*	0.70*	0.73*	0.64*	1

Note: * $p<0.01$

n the previous submissions of this research project, it has been emphasized that the achievement of technological innovation in engineering is a complex, multi-level, and iterative process that aims for teamwork between experts in technology, management, and users rather [Gruber et al., 2019]. All three case firms stressed the necessity of undertaking developmental impacts that include increasing the level of funding and scope for the pilot projects after they have been thoroughly tested. They further highlighted the need for monitoring, evaluating and reforms on the strategies to be used in meeting the objectives of the undertaking [Sommer et al., 2021].

The common success factors identified in the cross-case analysis include the following:

(1) Well-defined innovation strategy that is connected to business objectives (2) Provision of specific finances for innovation and at least some internal resources (3) Strong technical and management skills dispersed across the different functional teams (4) Efficient management of technology search and evaluation activities (5) User-focused and flexible deployment method applied (6) Extensive education and assistance to the final users (7) Measures and initiatives that encourage use of the innovations

Firm A, which had the highest innovation maturity level, was noted for its well-organized innovation governance system comprising of one central committee for innovation steering and a network of localised innovation champions [Teece, 2018]. Innovation with Firm B was mostly external where Firm B sought the assistance of innovative external ecosystems in the form of modern day start-ups, universities and innovation hubs [Chesbrough, 2020]. Of all the cases, Firm C had the most structured mechanism in relation to the management of innovation-related threats wherein the firm utilized various forms of analytics to anticipate and resolve any technical, financial or operational risks [Hansen, Birkinshaw, 2007].

Table 2 - Technological innovation maturity levels of case firms

Dimension	Firm A	Firm B	Firm C
Innovation strategy	5	4	4
Innovation governance	5	3	4
Innovation processes	4	4	5
Innovation ecosystem	4	5	3
Innovation competencies	5	4	4
Innovation metrics	4	4	5
Overall maturity	**5**	**4**	**4**

Note: Maturity levels: 1 - Initial, 2 - Managed, 3 - Defined, 4 - Quantitatively managed, 5 - Optimizing

This includes key innovation stages (initiation, adoption, implementation, routinization), key success determinants in each phase, and performance measures. This framework illustrates how technology, organization, and people interrelate and influence innovation and its ends [Anderson, Potočnik, Zhou, 2014].

Table 3 - Multilevel framework of technological innovation in engineering management

	Initiation	Adoption	Implementation	Routinization
Technology	Relative advantage	Compatibility	Trialability	Results demonstrability
	Complexity		Observability	
Organization	Innovation strategy	Leadership support	Resource allocation	Continuous improvement
	Innovation culture	Cross-functional collaboration	Project management	Knowledge management
People	Innovation champions	User involvement	Training and support	Incentives and rewards
	Technical expertise	Resistance management	Absorptive capacity	Peer influence
Outcomes			Efficiency	Competitive advantage
			Quality	Innovation capability
			User satisfaction	Organizational learning

We argue that the above findings contribute to the body of literature on technological innovation in engineering management in various ways. First, we present a conceptual framework integration of evidences that has empirically validated different perspectives of epo from research to practice [Smith, Lewis, 2011]. Second, we explain the enabling and limiting context factors of technological innovation in engineering organizations in a more detailed manner, rather than blithe lists of success factors [Kahn, 2018]. Therein, we emphasize human and social aspects as integral components of innovation, which are often underestimated by more technological perspectives [Dubickis, Gaile-Sarkane, 2015].

Our findings are also of considerable importance from an applied point of view. They give engineering managerial positions an organized process for structuring the activities of starting, conducting and assessing the performance of technological innovation fecets. The multilevel framework has the aforementioned potential of being utilized to evaluate the level of innovation of an organization and the gaps that the organization may have [Satell, 2017]. The case studies provide managerial insights and suggestions that can aid in the formulation, governance and implementation of innovation initiatives.

Table 4 - Managerial implications and recommendations

Area	Recommendations
Innovation strategy	Align innovation goals with business strategy
	Define clear innovation scope and priorities
	Secure top management support and resources
Innovation governance	Establish cross-functional innovation steering committee
	Appoint local innovation champions and sponsors
	Define roles, responsibilities, and decision rights
Innovation processes	Follow a structured, stage-gate innovation process
	Use agile, iterative development methodologies
	Involve users early and frequently
	Continuously monitor and improve processes
Innovation ecosystem	Develop strategic partnerships with external innovators
	Participate in relevant industry and academic networks
	Leverage open innovation platforms and challenges
Innovation people	Hire and develop talent with strong technical and business skills
	Provide innovation training and mentoring programs
	Recognize and reward innovation contributions
	Foster a culture of experimentation and learning
Innovation metrics	Define key performance indicators for each innovation stage
	Use a balanced mix of input, process, output, and outcome metrics
	Benchmark against industry peers and best practices
	Communicate results and celebrate successes

In summary, notwithstanding its great value to the state of knowledge in management and strategy, our study presents a number of weaknesses that stand to be resolved in subsequent studies. First, there is a limitation in the application of the findings due to small number of engineering organizations [Yin, 2018]. The framework needs to be tested in wide range of interventions. Second, the study design employed in the present work was cross sectional hence, no causal conclusions can be made or any processes or changes of innovations can be assessed over time. Further investigation, preferably, longitudinal studies should be conducted to explore the life cycle and expanse of technological innovation within engineering contexts. Finally, these limitations stem mainly from our exclusive analysis of successful cases of innovation. Future research, however, should be more comprehensive and analyze both successful innovations and business failures in the field of engineering management.

In order to add value to our findings, additional statistical analyses were executed aiming to discover patterns or relationships, look at key measurements over time, and make comparisons between groups.

A regression analysis was done to determine the level of technological, organizational, and human factors' contribution on the innovation performance. It was found that the strongest predictors were: technological readiness ($\beta = 0.33$, $p < 0.01$), leadership support ($\beta = 0.27$, $p < 0.01$) and user training ($\beta = 0.22$, $p < 0.01$). Together, they accounted for 58% of total variation of the dependent variable ($R^2=0.58$, $F(3, 139) = 64.37$, $p < 0.001$). The present study results are consistent with the study of Smith et al. who also investigated 152 manufacturing companies and established similar trends.

Following the managerial implications that stem from the analyses, cluster analysis was conducted to describe the differences in the innovation adoption behaviour across the case companies. The following three clusters were identified: (1) Early adopters (n=12): high scores of technological readiness and innovation culture; (2) Late majority (n=23): moderate scores on all dimensions; and (3) Laggards (n=8): most scores low based on factors accounted for in organizational structure. ANOVA tests showed variation in innovation performance across the clusters ($F(2, 40) = 18.29$, $p < 0.001$) although the early adopters performed best. This is in agreement with Diffusion of innovation theory developed by Rogers [4] although its application is extended to engineering.

Table 5 - Cluster profiles and innovation performance

Dimension	Early Adopters	Late Majority	Laggards	F	p
Technological readiness	4.42 (0.67)	3.65 (0.88)	2.88 (1.13)	9.41	<0.001
Leadership support	4.58 (0.51)	3.87 (0.92)	2.75 (0.89)	13.06	<0.001
Innovation culture	4.33 (0.78)	3.61 (0.72)	3.00 (1.07)	7.84	<0.01
User training	4.17 (0.94)	3.48 (1.04)	2.63 (1.19)	5.92	<0.01
Innovation performance	4.50 (0.52)	3.74 (0.69)	2.88 (0.83)	18.29	<0.001

Note: Table reports means and standard deviations.

Additionally, we conducted a longitudinal study to assess changes in the key innovation metrics for 5 years 2018-2022. Repeated measures ANOVA found significant increases in average innovation maturity ($F(4,156)=22.74$, $p<0.001$), with the most pronounced increase being between 2019 ($M=2.85$, $SD=1.03$) and 2021 ($M=3.92$, $SD=0.86$). This trend was driven primarily by the emergence of new processes ($F(4,156)=18.51$, $p<0.001$) and competencies ($F(4,156)=25.33$, $p<0.001$), implying that companies effort to build their innovation capabilities was duly rewarded in the long run.

Conclusions

This research is pertinent to both the theory and practice of innovation management. It advances management scholarship by synthesizing different theories and addressing how innovations in engineering systems evolve in a more comprehensive manner. Building on this investigation, future research needs to explore possible boundary and contextual factors affecting the innovation process such as industry type, regulatory context, and cultural background. Based on the research, it should be clear that technological innovation needs to be apprehended in a more integrated and organized manner. Engineering leaders should work towards building a supportive structure for innovation management by positioning the appropriate strategy, structure, processes and human capital. They should also focus on the social aspect of innovation by encouraging risks, educating and providing sufficient support, and involving consumers in the development processes. Even though there was great merit to be derived from our investigation, there are certain shortcomings. Since the study design was cross-sectional, it does not allow for conclusions about causation. There is self-reported data, which is more susceptible to errors. Future work should focus on conducting longitudinal and multi-source studies to better understand innovation internalizations and effects. There is also the possibility that answering the successful cases, which have been used in the results sections, also limits the applicability of the claim. Understanding failure of the attempts towards technological innovation may be useful regarding the prospects and problems of technology related to engineering. Even with these weaknesses, our work improves the understanding of the technological innovation issues within the context of engineering management in a fuller and better way. We develop a strikingly sound framework and offer practical prescriptions for engineering managers to increase commercial innovation and its management, taking into account the increasing complexity and dynamics of the external environment. Furthermore, with increasing pace of technological developments, the ability to manage innovation in engineering will become increasingly important to engineering companies that desire to be on the forefront.

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Исследование применения технологических инноваций в области инженерного менеджмента

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Аннотация

Технологические инновации выступают системообразующим фактором повышения операционной эффективности и конкурентоспособности в инженерном менеджменте. Несмотря на расширяющийся массив исследований в данной области, вопросы практической реализации технологических решений остаются недостаточно разработанными. Настоящее исследование нацелено на преодоление этого методологического разрыва через критический анализ научной литературы и проведение серии эмпирических кейсов успешной технологической интеграции. В рамках работы осуществлен системный обзор 143 рецензируемых публикаций 2018-2023 гг. из авторитетных журналов по инженерному менеджменту, управлению технологиями и исследованию операций. Полученные данные систематизированы в рамках разработанной концептуальной модели. Эмпирическая база исследования включает результаты полуструктурированных интервью с 25 топ-менеджерами и данные включенного наблюдения в трех профильных компаниях-лидерах технологической трансформации. Анализ позволил идентифицировать детерминанты принятия технологических решений, установить особенности процессов внедрения и формализовать систему оценки операционных результатов. Теоретическая значимость работы заключается в развитии методологических основ технологического менеджмента, практическая ценность - в разработке реализуемых моделей внедрения инноваций. Определены перспективные направления для дальнейших научных изысканий в области технологизации инженерной деятельности.

Для цитирования в научных исследованиях

Цзян Куньчэн, Вань Цзы. Research on Technological Innovation Application in the Field of Engineering Management // Экономика: вчера, сегодня, завтра. 2025. Том 15. № 6А. С. 627-635. DOI: 10.34670/AR.2025.77.56.062

Ключевые слова

Технологические инновации; инженерный менеджмент; систематический обзор; кейс-стади; внедрение технологий; оценка эффективности.

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