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Article

Developing Prototype of Piping Design Knowledge Management Systems in the Oil and Gas Industry

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Abstract. The limited acceptance of existing knowledge management systems within organizations necessitates enhancements to improve their effectiveness. This study addresses this issue by developing and evaluating a prototype of a piping design knowledge management system in the oil and gas industry. Utilizing a Design Science Research (DSR) methodology, the research identified key system requirements through theoretical analysis and structured interviews with representative users across various functional roles. Based on these insights, a prototype emphasizing knowledge retrieval and creation functionalities was developed and empirically tested against the existing system. The results indicate significant improvements, including increased success rates, enhanced system usability (with average system usability scale scores rising from 36.10 to 78.20), and high technology acceptance (81%). Furthermore, the new system eliminated lostness, reduced average knowledge retrieval time from 52.68 to 46.51 seconds, and significantly decreased knowledge creation time from 229.81 to 93.68 seconds. These findings demonstrate the potential of the proposed system to enhance organizational performance, suggesting broader applicability across engineering departments.

Keywords: Piping design, knowledge management system, usability evaluation, technology acceptance model 3.

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1. Introduction

Knowledge Management (KM) refers to the systematic processes of capturing, distributing, and effectively utilizing knowledge within an organization [1]. Its fundamental objective is to ensure the provision of the right information to the appropriate individuals at the right time, thereby enabling informed decision making [2]. According to Arthur Anderson Business Consulting, KM encompasses not only knowledge acquisition, integration, storage, sharing, transfer, application, innovation, but also involves strategic leadership, corporate culture alignment, performance evaluation, and the strategic deployment of information technology [3].

The 2021 Global Human Capital Trends Survey highlights that frequent employee mobility, whether within the same department, across different departments, or between organizations, is driving the adoption of proactive KM strategies. Specifically, 52 percent of respondents identified internal employee movements as catalysts for KM development, whereas 35 percent indicated that frequent staff changes could impede effective KM [4]. Regardless of the underlying drivers, effectively implemented KM processes yield tangible organizational benefits, notably reducing the time required for new employees to achieve competence. Prior research further underscores KM's positive impact on optimizing organizational resource utilization and enhancing overall organizational performance [5].

The development of a knowledge management systems (KMS) is a multifaceted and evolving research domain. Within the field of information systems, the Design Science Research Methodology (DSRM) is recognized as a robust and widely adopted framework [6, 7]. DSRM is particularly noted for its effectiveness in the systematic design, development, and evaluation of technological artifacts, including guidelines for KMS design. Given that the efficacy of a KMS significantly impacts an organization's ability to achieve its strategic objectives, its thoughtful design and development are critical yet challenging tasks. In the present study, similar challenges and objectives characterize the current KMS under investigation, highlighting the imperative need for an improved and specifically tailored KMS. The limited organizational acceptance of the existing system necessitates enhancing its effectiveness. An upgraded KMS promises not only to facilitate employee training and enhance their technical skills but also to serve as a valuable model for implementation across other engineering departments.

1.1. The Case Study Company

The organization examined in this case study is a technical engineering consulting firm operating within the oil and gas industry. The company delivers specialized engineering services through the collaboration efforts of ten distinct engineering departments. Presently, the organization stores its knowledge resources on an internal server, structured into individual folders corresponding to each department. Access to these departmental folders is restricted exclusively to personnel within the respective departments.

Within each department's folder, additional sub-folders are systematically created to manage knowledge resources effectively. These sub-folders are categorized based on temporal parameters, specifically into yearly, quarterly, and monthly segments. Knowledge documents, shown in **Fig. 1** and predominantly in Portable Document Format (PDF), produced during departmental projects, are archived monthly within the relevant folders. The volume of knowledge documentation varies according to the insights gained during project execution. Employees utilize these knowledge resources to maximize project outcomes, relying on systematic file organization for effective retrieval.

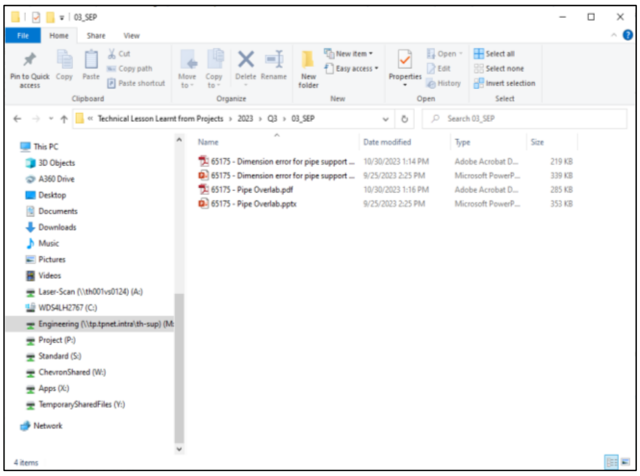

Fig. 1. Knowledge storage for the case study company at present.

To standardize knowledge documentation, the organization has implemented a structured template for creating knowledge artifacts. Each PDF file adheres to this predetermined format (**Fig. 2**), which includes clearly identified sections such as a lesson title and reflective questions, for instance, "What happened?", "Why did it happen?", and "What needs to be done differently?" Despite these measures and organizational guidelines, employee acceptance of the existing Knowledge Management System (KMS) remains low. In 2023, evaluations conducted by the company indicated inconsistencies in knowledge documentation across departments, with several units failing to meet the minimum requirement of recording new knowledge at least once per month. Additionally, internal policy emphasizes balancing project bids and maintaining an optimal employee age profile by recruiting recent graduates to support international projects. However, these newly graduated employees typically possess limited practical experience and technical knowledge, thereby highlighting the critical importance of an effective KMS.

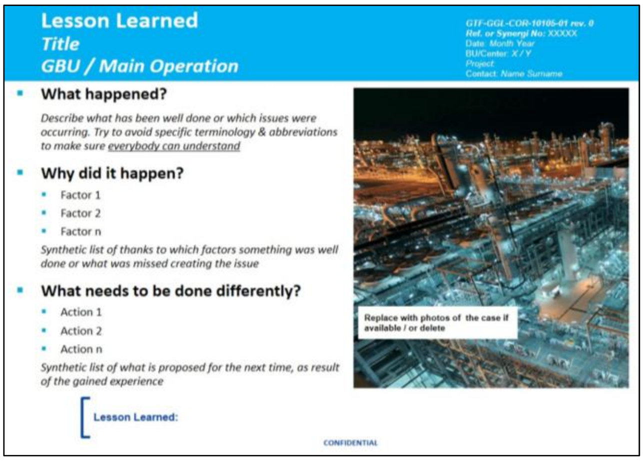

Fig. 2. A structured template for creating knowledge artifacts.

Acknowledging these challenges, the case study organization recognized the necessity to design and implement a new KMS capable of effectively facilitating knowledge creation, representation, storage, retrieval, and practical application [8]. The intended outcome of this redesigned system is improved employee acceptance, which would subsequently enhance technical skills development and training efficiency.

Given the significance of the ongoing challenges related to the low acceptance of the existing KMS, coupled with the imperative to enhance employee technical proficiency, a thorough analysis of the current KMS was conducted. Findings revealed significant deficiencies, notably the absence of clearly defined success factors, comprehensive guidelines, and explicit requirements for effective KMS design. As a result, this study specifically targets improvements in the KMS for the piping department, selected because it is the largest departmental unit within the firm and employs the highest number of engineers. Enhancing the effectiveness of the piping design KMS is anticipated to serve as a prototype for subsequent adoption by other engineering departments within the organization. Therefore, the primary objective of this study is to design and develop a novel piping design KMS prototype. The goals are (1) to address knowledge loss due to retiring engineers, (2) to improve efficiency in retrieving design knowledge, and (3) to increase user acceptance by incorporating usability and trust mechanisms. Employee acceptance of the system will be assessed through simulated usage scenarios and evaluated its usability, for both system performance metrics and self-report metrics using System Usability Scale (SUS) and the Technology Acceptance Model 3 (TAM3). This research contributes to academia by applying the Design Science Research Methodology (DSRM) in a complex engineering context, offering a structured and iterative approach to artifact development and validation. It contributes to industry by providing a practical, adaptable system that integrates with existing workflows and enhances knowledge retention, especially in departments highly reliant on expert know-how.

2. Methodology

The Design Science Research Methodology (DSRM), introduced by Peffers et al. (2007) [7], has been widely adopted in KMS development across various domains, such as assembly assistance systems [9], cultural heritage projects KMS [10], and railway infrastructure manager KMS [11]. These studies demonstrate DSRM's capacity to support iterative, evidence-based artifact development, especially when system usability and organizational integration are critical. In this study, also selected DSRM due to its structured process model that supports both the creation and validation of technical artifacts in complex environments. The iterative nature of DSRM aligns well with engineering development practices and allows for rigorous, feedback-driven refinement of system features based on stakeholder input.

The piping design KMS follows a design based on DSRM [7]. The design consists of the following five activities: 1.) Identifying the problem and motivating it begins with the identification and specification of system design requirements. These requirements were systematically derived using two complementary approaches: theoretical analysis of existing literature and structured interviews with representative user samples. 2.) Define the objectives of the solution based on the synthesis of these requirements. 3.) Design and development of a prototype of the piping design KMS. 4.) The demonstration was constructed and developed a prototype using a tool for user interface design. Subsequently, 5.) Evaluation: The prototype underwent systematic evaluation to assess its efficacy in addressing the identified design objectives. The detailed phases and specific activities involved in this methodological approach are elaborated as follows.

2.1. System Requirements

This research examines the protocols and requirements essential to effective KMS design, emphasizing criteria proposed by prior research [12]. Grounded in established KMS success factors, the design criteria address three critical perspectives:

(1) *Supporting Organizational Knowledge Management Processes.*

An effective KMS must support key organizational KM processes. Researchers consistently propose several core KM activities, including knowledge creation, storage, retrieval, transfer, and application [8, 13, 14]. Analysis of the existing system within the case study organization revealed deficiencies in fundamental functions, notably in knowledge creation and storage capabilities. Thus, the proposed KMS requires enhancements in these foundational processes, alongside the integration

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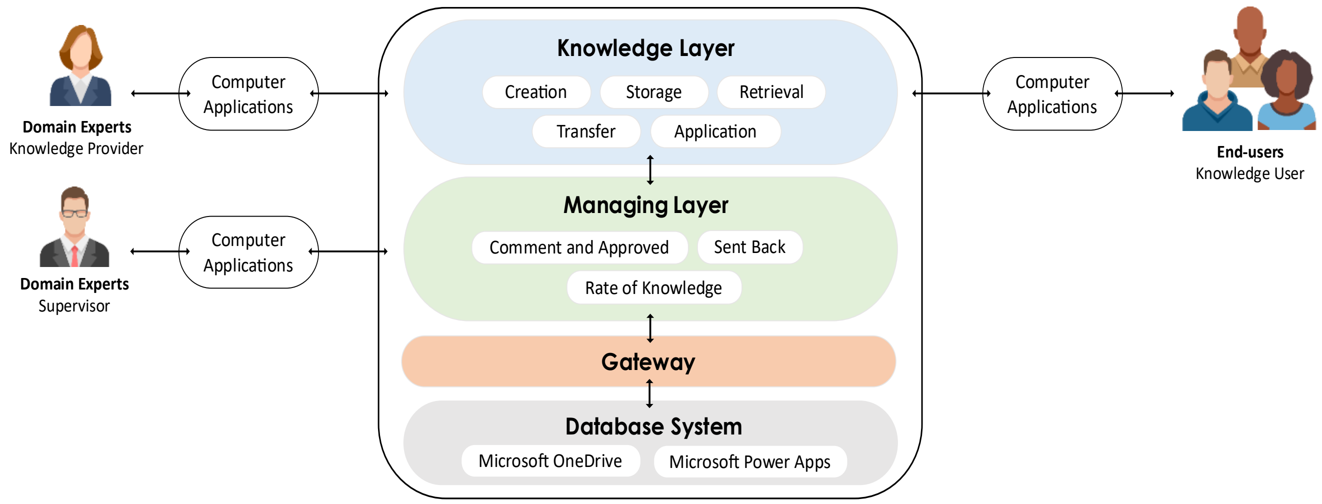

Fig. 3. System overview of the piping design knowledge management system.

of other essential KM functions—such as retrieval, transfer, and application—to ensure comprehensive KM support.

(2) *Mechanisms for Trust and Recognition of Contributions*

An effective KMS should incorporate mechanisms that facilitate trust and recognize individual contributions. Literature emphasizes that such systems must allow users to provide feedback to knowledge providers, specifically concerning the impact and usefulness of the knowledge shared. This feedback mechanism is crucial for enhancing user engagement and encouraging greater knowledge-sharing behavior [15]. Furthermore, mechanisms providing users with clear indicators about the source, reliability, and quality of the knowledge, as well as recognition for contributors' efforts are essential [12]. The existing KMS in the case study company currently lacks these mechanisms, necessitating substantial improvements to foster employee trust, recognition, and active participation.

(3) *Personalized Knowledge Delivery Aligned with User Needs and Complexity of Knowledge*

The KMS design must facilitate personalized knowledge delivery based on individual user requirements, backgrounds, and the complexity of the knowledge involved. Additionally, the KMS should dynamically respond to personnel changes and evolving knowledge requirements within the organization. Personalized knowledge flow ensures that users efficiently access information tailored specifically to their roles and expertise, enhancing overall system usability and effectiveness [16]. The current KMS of the case study organization does not adequately support personalized knowledge delivery, thus underscoring an area for significant improvement.

The design process began by reviewing these three fundamental criteria from theoretical perspectives to identify critical functionalities and system requirements. Based on these insights, an initial mock-up of the piping design KMS was developed. This preliminary system served as a first iterative design tool used for conducting semi-structured interviews with representative users to capture additional user-based requirements and feedback. Insights gathered from these interviews were subsequently analysed and integrated into the prototype design for the mock up, ensuring alignment with the diverse needs of users across various roles.

Following the user-based requirement interview, a refined mock-up of the piping design KMS was developed to accurately reflect user-identified requirements. The finalized mock-up underwent further evaluation during structured interviews, where users compared the new system directly with the existing KMS, particularly focusing on structure, functionality, and usability by looking into the current KMS first. A crucial aspect of this evaluation involved validating the knowledge definitions incorporated into the new system. Users assessed whether these definitions aligned appropriately with their understanding and requirements, a critical step in ensuring system adoption.

The semi-structured and final structured interviews involved five participants from three distinct user roles within the piping department, a group of actual system users: One manager of the piping department, who functions as the system supervisor: Two senior piping engineers, who act primarily as knowledge providers: Two piping engineers, who primarily act as knowledge users.

Interview outcomes indicated agreement among participants across all roles that the new system mock-up adequately addressed both theoretical requirements and practical user needs. Specifically, users recognized that clearly articulated and consistent knowledge definitions significantly facilitated effective knowledge creation and retrieval. Subsequently, knowledge matching tests were

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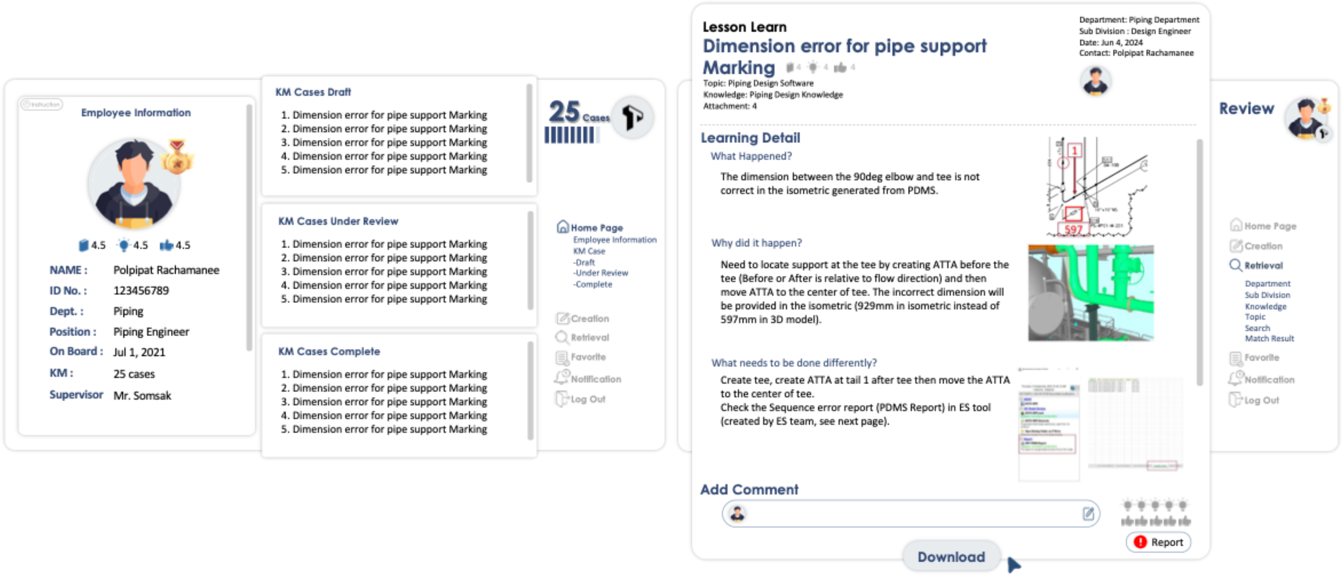

Fig. 4. A prototype of a piping design knowledge management system.

performed, comparing user-generated content with established system definitions. These results provided further refinements to knowledge definitions and topic selections, effectively informing the subsequent design and development stages of the piping design KMS. The system overview of the piping design knowledge management system is shown in **Fig. 3**.

2.2. System Design Prototyping

The high-fidelity prototyping process began after finishing with the process of getting the requirement of the KMS tailored specifically to piping design. This aimed to fulfill both theoretical requirements and practical needs identified by system users. An overview of the conceptual structure of the proposed piping design KMS is presented in **Fig. 3**.

The architecture of this KMS is based on knowledge originates from domain experts, defined as knowledge providers, who share expertise through dedicated computer applications. The knowledge layer comprises core functional activities essential for effective knowledge management, including knowledge creation, storage, retrieval, transfer, and application. The shared knowledge resources are subsequently made accessible to end-users, categorized as knowledge users, ensuring effective dissemination within the organization. The functionality of computer applications is structured to operate concurrently within this knowledge layer. Additionally, knowledge content must undergo validation by supervisors, typically domain experts, who utilize dedicated computer applications for verification and approval.

Beyond the knowledge layer, the system integrates a management layer, responsible for overseeing knowledge-related processes. Management layer functionalities include providing feedback through comments, approval or rejection (sent backs), and assigning ratings to knowledge contributions. Both knowledge and management layer activities operate through a gateway that serves as an intermediary, facilitating seamless connectivity with the underlying database. Data within the piping design KMS are stored using Microsoft OneDrive, while system applications are developed utilizing Microsoft Power Apps to ensure robust functionality and efficient user interaction.

To effectively illustrate and evaluate the proposed piping design KMS, a detailed interactive prototype was created (**Fig. 4**) using the user interface design tool, Figma. The selection of Figma is justified based on its wide acceptance as a leading interface design tool, recognized as the most popular tool in 2022 and consistently among the top three design tools since 2019 [17, 18]. The principal features include (1) structured knowledge submission forms for input standardization; (2) an integrated approval workflow to ensure content quality and reliability; and (3) feedback and rating mechanisms to foster trust in shared knowledge. The prototype addresses gaps in the existing system: insufficient structured templates for design knowledge input, low system usability leading to poor adoption, and the lack of quality control and approval mechanisms. This system implements role-based workflows, feedback mechanisms, and knowledge approval to mitigate limitations and addresses piping design challenges, including (1) fragmented and inconsistently formatted knowledge documents, (2) challenges in accessing expert knowledge from previous projects, and (3) lack of quality assurance mechanisms in shared technical knowledge. The system facilitates expedited knowledge reuse and enhanced design consistency through the integration of workflows, templates, and role-based access. The primary objective of prototyping was to conduct comprehensive usability testing, ensuring that the developed KMS effectively addresses both theoretical criteria and practical user requirements. This usability evaluation was central to validating the system's effectiveness, functionality, and alignment with user expectations.

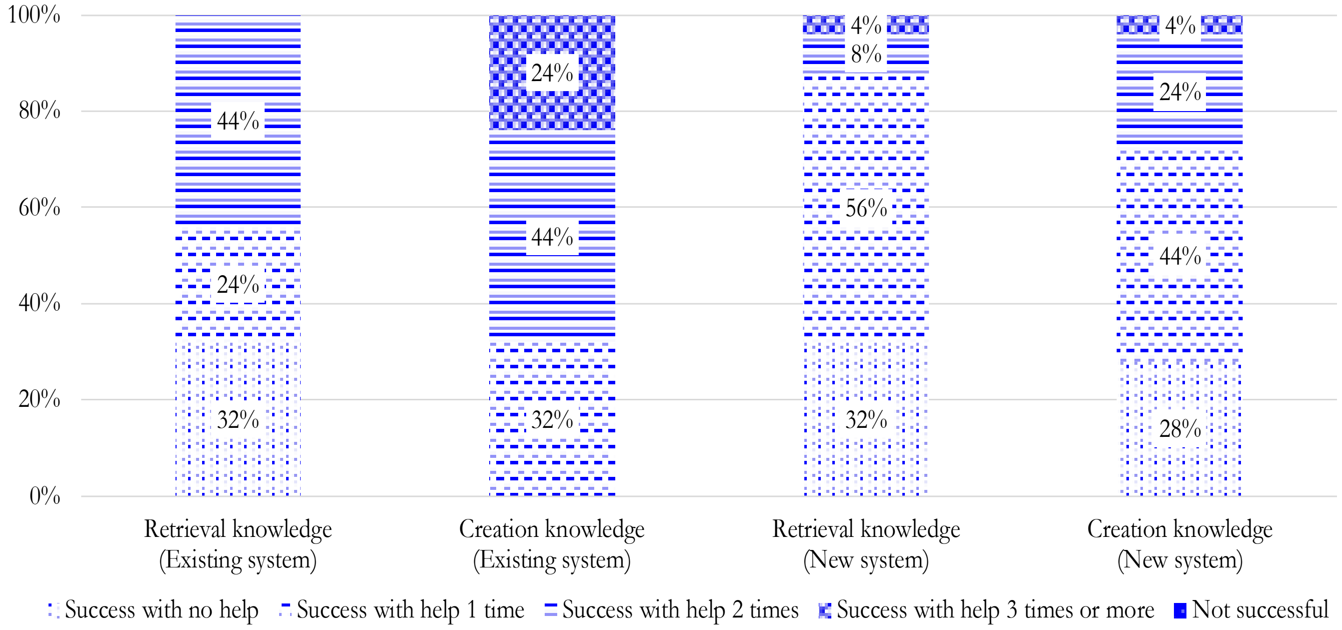

Fig. 5. Partial success analysis of knowledge retrieval and knowledge creation in existing KMS and new KMS.

2.3. Design Validation

This study evaluates the effectiveness of both the existing Knowledge Management System (KMS) and the newly developed prototype specifically designed for piping design tasks. A total of 25 piping design engineers participated in the validation study, comprising 80% male participants. The participants were categorized into two age groups: 60% were between 21–40 years, and 40% were between 41–60 years. The sample included one piping department manager, sixteen senior piping engineers, and eight piping engineers.

A within-subject experimental design was employed, enabling each participant to evaluate both the existing system and the newly developed prototype in random order. Randomization was utilized to control potential learning effects and ensure unbiased comparative evaluation. Five usability metrics were employed to assess system effectiveness comprehensively: performance-based metrics including success rate, lostness [19], time on task, and self-reported measures comprising the System Usability Scale (SUS) [20] and Technology Acceptance Model 3 (TAM3) [21, 22, 23].

Usability testing sessions were conducted individually in a private meeting room using the researcher's laptop computer. Each session began with an explanation of the study objectives and the collection of informed consent from each participant. Participants were randomly assigned task sequences, initially testing knowledge retrieval or knowledge creation functionalities in either the existing system or the new prototype. Upon completing these tasks, participants filled out evaluations using SUS and TAM3. Subsequently, participants performed identical tasks in the alternative system and repeated the evaluation process. The average total duration of each usability testing session was approximately 23 minutes.

Table 1. The descriptive statistic.

Metrics	N	Existing system		New system	
		Retrieval	Creation	Retrieval	Creation
Success rate (%)	25	32%	0%	32%	28%
Lostness *M (SD)*	25	0.16 (0.17)	0.08 (0.13)	0.00 (0.00)	0.00 (0.00)
Time on task (s) *M (SD)*	25	52.68 (0.33)	229.84 (0.34)	46.51 (0.30)	93.68 (0.21)
SUS *M (SD)*	25	36.10 (17.19)		78.20 (9.96)	
TAM3 (%)	25	48.8%		80.9%	

3. Results and Discussion

The usability testing results are reported across three key dimensions: system effectiveness, assessed by success rate and lostness; system efficiency, measured by time on task; and system satisfaction, evaluated using the SUS and the TAM3. A summary of the descriptive statistics is provided in **Table 1**.

3.1. System Effectiveness

The evaluation of system effectiveness was based primarily on success rates and lostness observed during usability tests involving 25 participants. The success rate analysis indicated that all participants successfully completed the assigned tasks. However, assistance required by participants during task completion varied

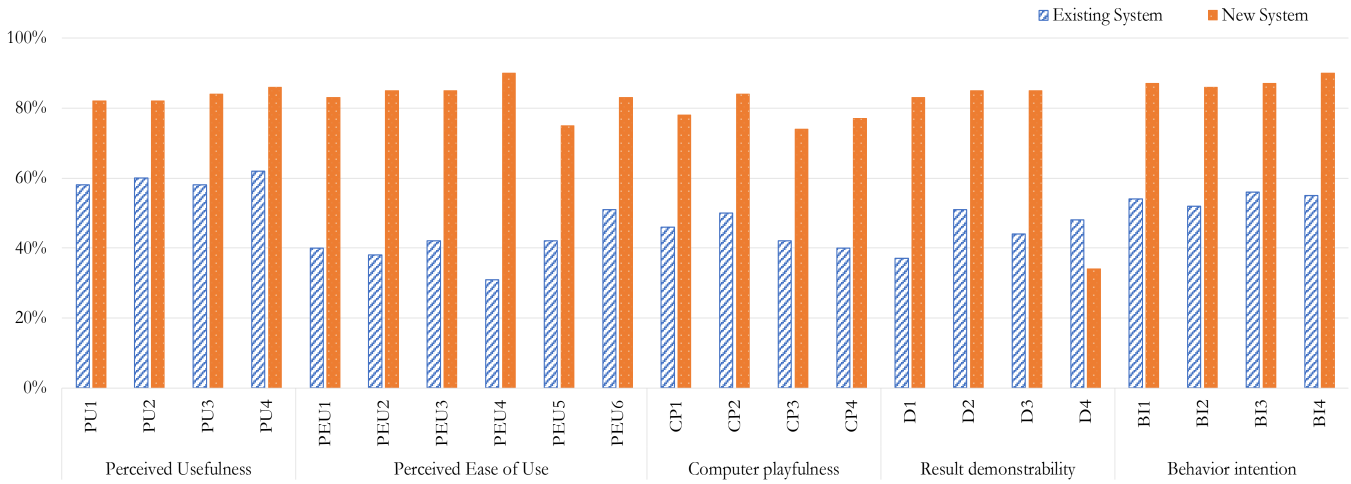

Fig. 6. Evaluation results of technology acceptance model 3 in existing system and new system.

between the existing and new KMS as shown in **Fig. 5** the partial success analysis.

Analysis of the success rate (success with no help) indicated that both systems supported independent completion of knowledge retrieval tasks equally well. However, the new KMS significantly reduced the frequency and intensity of required assistance compared to the existing system. Although participants were familiar with the existing system, likely influencing their independent performance, the lower overall assistance required for the new system indicates enhanced intuitiveness and ease of use for first-time interactions. This reflects the improved user-centric design, specifically targeted to facilitate seamless navigation and interaction.

For knowledge creation tasks, the new KMS exhibited clear advantages. Participants frequently required minimal or no assistance, indicating the new system's effective design in guiding users through knowledge creation without extensive training or repeated intervention. In contrast, the existing system, reliant on manual formatting using external software such as PowerPoint, consistently demanded greater cognitive effort and technical intervention, substantially impacting user performance and efficiency.

The lostness analysis further underscores the benefits of the newly designed KMS. The new system showed no evidence of internal navigational confusion or operational uncertainty, highlighting its intuitive, user-friendly structure. Conversely, the existing system's measurable lostness, although still relatively low. Notably, one participant experienced significant lostness (0.50) in the existing system during a retrieval task. This indicates challenges in user navigation despite prior familiarity, suggesting structural or interface limitations that hinder usability and efficiency.

Collectively, these findings validate that the newly developed piping design KMS substantially enhances user effectiveness through reduced assistance requirements and minimized navigational complexity, thereby better supporting efficient knowledge retrieval and creation processes.

3.2. System Efficiency

System efficiency was evaluated through the metric of time on task, comparing knowledge retrieval and creation tasks in the existing and new KMS. The evaluation showed no significant difference, with a p-value equal to 0.146 at a 95% confidence level in the average time required for knowledge retrieval between the new system (46.51 seconds) and the existing system (52.68 seconds). This minimal difference was contrary to initial expectations. A possible explanation for this finding is that participants relied on predefined chronological structures (yearly, quarterly, monthly folders) and specific file names available in the existing system, allowing rapid knowledge retrieval during test conditions. However, it is important to note that in actual practice, users may not precisely recall the dates or specific file names, potentially extending real-world retrieval times beyond those observed during controlled testing.

For knowledge creation tasks, the new system significantly outperformed the existing system, with average completion times dramatically reduced from 229.81 seconds to 93.68 seconds, with a p-value of approximately 0.000 at a 95% confidence level. This substantial improvement is attributable to the new system's automatic formatting and structured guidance, eliminating manual formatting tasks and simplifying the process, thus directly reducing the cognitive and operational effort required from users.

3.3. System Satisfaction

System satisfaction was measured using two self-report metrics: the SUS and the TAM3. SUS was used to assess overall system usability through a 10 questionnaire with alternating positive and negative statements.

Example items included: "I thought the system was easy to use" and "I found the system unnecessarily complex." Respondents rated each question on Likert scale ranging from "Strongly Disagree" to "Strongly Agree." SUS results revealed a significant improvement in perceived usability, with a *p*-value of approximately 0.000 at a 95% confidence level, with the new system scoring 78.20 points (B+ usability rating), substantially higher than the existing system's average of 36.10 points (F usability rating). According to the usability guidelines by Sauro and Lewis (2012) provided in **Table 2**, the existing system's usability was classified as unsatisfactory, indicating significant user dissatisfaction, whereas the new system's rating was well within the acceptable usability range [20].

TAM3 was employed to assess factors influencing system acceptance, including perceived usefulness (PU), perceived ease of use (PEU), computer playfulness (CP), result demonstrability (D), and behavioral intention (BI). Example statements included: "Using the system improves my job performance" (PU), "The system is easy to learn" (PEU), and "I intend to continue using the system" (BI). Responses were also recorded using Likert scale, and evaluation through TAM3 (**Fig. 6**) highlighted strong user acceptance of the new system across multiple dimensions. The overall acceptance rate for the new system reached approximately 81%, suggesting high willingness among piping engineers (approximately 20 out of 25 participants) to adopt the redesigned KMS for daily knowledge sharing activities. The perceived usefulness and perceived ease of use scores both attained notably high ratings (84% each), indicating that participants recognized significant benefits and ease associated with the new system. Additionally, participants demonstrated positive attitudes towards computer playfulness (CP:78%), result demonstrability (D:72%), and a high behavioral intention (BI:88%) to continue using the system.

Table 2. Interpreting SUS scores.

	SUS Score Range	Grade	Percentile Range
Acceptable	84.1-100	A+	96-100
	80.8-84	A	90-95
	78.9-80.7	A-	85-89
	77.2-78.8	B+	80-84
	74.1-77.1	B	70-79
	72.6-74	B-	65-69
Marginal	71.1-72.5	C+	60-64
	65-71	C	41-59
	62.7-64.9	C-	35-40
	51.7-62.6	D	15-34
Not	0-51.7	F	0-14

These findings collectively emphasize that the newly developed piping design KMS effectively addresses previous challenges related to system adoption, significantly improves overall user satisfaction, and aligns closely with the identified technical capability enhancement needs among employees. The prototype significantly enhanced usability and efficiency within the piping department by providing a streamlined, structured process for knowledge creation and retrieval. Users reported faster access to previous designs and greater confidence in shared knowledge due to the approval mechanism. While the system was designed for the piping department, its modular architecture and role-based workflow model make it adaptable to other departments, such as the instrument or civil department, where specialized knowledge is critical. Furthermore, the prototype aligns with Nova et al. [10], who highlighted that cultural heritage KMS benefited from modular, role-oriented content delivery, a feature mirrored in this prototype.

4. Conclusion

This study aims to design and develop a prototype of a piping design KMS tailored for the oil and gas industry. The research followed the DSRM, using both theoretical analysis and user interviews to identify system design requirements. Three key success factors were defined to guide development: (1) the KMS should support core organizational knowledge management processes; (2) it should include mechanisms to build trust, recognize contributions, and encourage participation; and (3) it must facilitate knowledge flow based on users' roles, backgrounds, and the complexity of knowledge.

Guided by these principles, a prototype piping design KMS was developed and tested with actual users. The system focused on two primary functions: knowledge retrieval and creation. Results from usability testing and comparative analysis with the existing system demonstrated that the new system significantly improved success rates, usability, and user acceptance. The average usability score increased from 36.10 (unacceptable, F range) to 78.20 (acceptable, B+ range), and the technology acceptance rate reached 81%. Additionally, the new system eliminated lostness to zero and reduced task completion times: retrieval time dropped from 52.68 to 46.51 seconds, and creation time from 229.81 to 93.68 seconds.

These findings suggest that the newly developed prototype not only enhances efficiency and usability but also better supports employee learning and knowledge-sharing behaviour. While initially implemented in the piping department, the system architecture and design methodology can be extended to other engineering departments. The system is expected to serve as a foundation for improved employee training, technical competency development, and ultimately greater organizational and customer outcomes.

While the results are promising, this study has certain limitations. First, the prototype was tested in a controlled environment with a relatively small group of participants from a single department, limiting the generalizability of the findings. Second, due to time constraints, the system was developed and evaluated in a limited design iteration. As a result, although the prototype demonstrated improved performance, there remains significant potential for further refinement. With more time and iterative design cycles, the system could be improved in several aspects, including interface personalization, integration of tacit knowledge capture, and deeper support for cross-departmental knowledge sharing.

Future work should focus on extending the system's evaluation to broader organizational contexts and over longer timeframes to observe sustained usage patterns and real-world impact. Additionally, iterative development involving user feedback at each stage will help optimize system features and usability. Exploring advanced technologies, such as AI-assisted search and recommendation engines, could further enhance the system's adaptability and intelligence. These technologies could automate knowledge extraction, personalize content delivery, and increase knowledge reuse—especially in complex design environments. Another promising direction is the implementation of the KMS prototype in other engineering departments, such as the instrument department. This would allow for cross-departmental knowledge integration and reveal department-specific customization needs, contributing to a more holistic enterprise solution. Ultimately, a more comprehensive, scalable KMS solution may be achieved through continued co-design with users and iterative improvement based on practical deployment. Co-designing with actual users and applying iterative refinement based on real-world deployment can ultimately lead to the development of a scalable, intelligent, and organization-wide knowledge management solution.

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