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Digital transformation in the context of maintenance management systems in SMEs: critical factors and empirical effects

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Abstract

Nowadays, digital transformation is an inevitable measure in all industries to reap the benefits of Industry 4.0, and so all Small and Medium-sized Enterprises (SMEs) also, strive to digitize their detrimental functions to their sustained growth. As the digitization triggers real-time data capturing, the introduction of efficient Predictive Maintenance (PdM) schemes in Maintenance Management (MM) becomes feasible, improving operational efficiency. The challenging problem is to correctly identify the factors that will influence the successful implementation of digitization of Maintenance Management System in SMEs. This research focuses on enlisting, evaluating and identifying the most influential factors for implementing digitization in MM system of SMEs. In this work, a Q-methodology based solution methodology is proposed to find the critical factors for the implementation. The Q Set is developed through a well-designed interview process, and an on-line survey software is employed to rank and sort the Q statements both qualitatively and quantitatively, followed by a structured statistical analysis. Out of the five factors that evolved in the process, two factors were identified as influential for the implementation. The proposed methodology is applied to a few SMEs with similarities, and the results obtained exhibit consistency in validating the proposed methodology's accuracy. The proposed methodology is compared with that of similar Q based methodologies reported in the literature, and the proposed methodology is found to be more efficient.

Keywords: *digital transformation; maintenance management system; predictive maintenance; Q-methodology; small and medium-sized enterprises.*

1. Introduction

Digital transformation activities, such as manufacturing, supply chain, quality testing, human resource management, service, maintenance and so on, are currently of great interest to all Small and Medium-sized Enterprises (SMEs) (Terdpaopong, 2011). Especially in situations like pandemic COVID-19, SMEs cannot afford to run their daily routine production for months together without adequate profit and so are forced to slow down or stop their business activities, reduce the product range and retrenchment of employees. Due to the sudden decrease in the number of customers in the retail store and the unavailability of digital connectivity (Terdpaopong, & Al Farooque, 2011), SMEs end up specializing in a few products and on-line selling with a limited market segment. Complete or at least partial digital transformation of the above-mentioned industrial activities seems to be a great solution for such SMEs

(Kanchanaharuthai, & Boonyaprapasorn, 2011). The order of the day is that all the manufacturing industries worldwide, driven by the pandemic situation, are focusing on digital transformation in the context of the European Union's Green Deal. Digital transformation denotes Industry 4.0 encompassing the key elements like Internet of Things (IoT), Cyber-Physical Production Systems, Cloud Computing (CC), Data Mining, Machine Learning Algorithms (MLA) and Augmented Reality. With the effective digitization, in Industry 4.0, for the better upkeeping of the production facilities, the Predictive Maintenance (PdM) of equipment, which is based on the real-time behavioral data of types of equipment, is becoming more beneficial than the conventional preventive maintenance based on a predetermined fixed maintenance schedule and interventions.

This research mainly focuses on the digital transformation of maintenance management in SMEs that will facilitate the effective implementation of the PdM process. As this process will predict the probable failures or occurrence of any fault in machine components, the maintenance problems are rectified before they occur and while the manufacturing operations are on. This results in optimal maintenance activities leading to maximum profit and customer satisfaction in manufacturing industries (Aggarwal, Kumar, Singh, & Garg, 2015). SMEs are no exemption; they are willing to adapt to this smart autonomous, digitally transformed working environment to fetch more sustained profit and greater customer satisfaction.

The main objectives of this research work are to identify, evaluate, and unveil the most critical factors that will influence the successful implementation of the digital transformation of the MM system in SMEs. In this work, Q-Methodology approach is chosen to find the critical parameters, involving both the real-time operation and maintenance crew and academic experts in formulating the Q-sets and grouping them into Factors (Lee, 2017). An on-line survey with another set of real-time maintenance crew in industry and academic experts were utilised in the on-line survey, and subsequent qualitative and quantitative analysis was done by the Q-Method Software used in this work. The output of the analysis was validated with the operating crew of the case study industry through the interview method.

This research article is structured in five sections. The first section gives an introduction to the purpose of this research work. The second section presents the related research articles concerning chosen research problem and solution methodology adopted in this work. The third section deals with the problem definition, objective, data collection, and solution methodology. The fourth section presents the analysis of results obtained and discussions there forth. The final section presents the conclusions of the research finding and provides direction for future research in this research area.

1.1 Literature review

In the recent past, research in the field of maintenance management in all manufacturing systems ranging from small job shops environment to flexible manufacturing cells has focused on the use of event-driven analysis, condition-based monitoring models and predictive maintenance programs (Hribernik et al., 2018) to achieve optimal maintenance, maximum availability, minimum maintenance over-heads (Bousdekis, Papageorgiou, Magoutas, Apostolou, & Mentzas, 2017; Nzukam, Voisin, Levrat, Sauter, & Iung, 2018), maximum overall efficiency (Velmurugan, Venkumar, & Sudhakara, 2021a & 2021b) and customer satisfaction (Pandian, & Soltysova, 2018). PdM is modelled as a knowledgebase system equipped with data capturing and mining on real-time data. Industries aspiring for digital transformation matching with Industry 4.0, PdM based maintenance system supported by machine learning algorithms and cloud computing technology becomes mandatory (Ruiz-Sarmiento et al., 2020; Lee, 2017; Fernandes et al., 2019). Hence, for all industries, especially small and medium scale enterprises that form the major chunk of manufacturing sectors, the implementation of digitization in the maintenance management system will enable the implementation of real-time data-driven predictive management schemes to improve overall performance and sustained growth of any manufacturing systems.

In any system aiming for a paradigm shift in philosophy and technological turn arounds, all the operating personnel collectively loo into the pros and cons, the factors and constraints that will be detrimental to the change and detect the critical factors that need to be dealt with the successful implementations. Traditionally in such scenarios, the Q Methodology (Lee, 2017; Damio, 2016, Dziopa, & Ahern, 2011) has been the most successful tool, especially where the opinions and/or decisions involved are subjective and more qualitative in nature (Lundberg, de Leeuw, & Aliani, 2020; Sneegas et al., 2021). Besides, traditionally it has been widely used in research in the area of medicines, nursing care and philosophy (Kostenzer, Bos, de Bont, & van Exel, 2021; Barbosa et al., 2020; Sheykhfard, Haghighi, Soltaninejad, & Karji, 2020) for the improvement of mental health, introduction of new drugs and so on. Recently Q Methodology has been applied in other research domains, such as perspectives of eco-systems (Hermelingmeier, & Nicholas, 2017; Lee 2021), evaluating decision-making systems (Nahm, Rao, Solis-Galvan, & Ragu-Nathan, 2002; Davis, & Michelle, 2011), road safety measures based on with drivers/transporters mental endurance and so on. Newer and newer models of Q Method are being evolved to make decisions based on more quantitative and qualitative analysis (O'Leary, Wobbrock, & Riskin, 2013; Cao, Zanni-Merk, Samet, de Beuvron, & Reich, 2020; Moser, & Baulcomb, 2020). From the survey, it has been observed that the application of Q Method in the manufacturing research domain is yet to begin, especially in making decisions or finding critical facts involving human opinions, for a better and hurdle-free process for successful implementations. Similarly, (Bartlett, & DeWeese, 2015) described the utilization of Q methodology in the human resource development field, and Rahma, Mardiatno, and Hizbaron (2020) presented the factor analysis of the education development field through the same analysis approach.

2. Objective

The main objective of this work is to identify the critical factors that will be influential while implementing the digitization of the maintenance management system, applying a solution methodology, and conforming to the Q Methodology framework. In this work, the main research focus is an easier and more successful implementation of digital transformation in the maintenance management system of industries more specific to SMEs, facilitating more reliable and real-time data acquisition and mining to reap the full benefit upon implementing predictive maintenance plans.

3. Problem and solution methodology

3.1 Sampling and data collection

The research focuses on the digital transformation of maintenance management systems in SMEs to achieve optimal operating efficiency and sustain growth. The research problem is to identify the critical factors that will facilitate the successful implementation of digital transformation and reap the full potential of the same through its features like real-time supported predictive maintenance tool.

This research aims to identify, evaluate, and unveil the most critical and influential factors for the implementation of the digital transformation, converting the maintenance management system into an intelligent and autonomous working environment.

The solution methodology conforms to the Q-methodology, which involves the formulation of Q-Sets with the active participation of the practical and academic experts concerned. An on-line survey with the participation of maintenance and operating personnel of a case study industry is followed by a software-driven statistical analysis of data. The procedural steps of the methodology used are as below:

Step 1: Identifying and list all the factors that will favor the digital transformation and factors that may constrain the implementation.
Selecting the industry for the case study and operating and maintenance personnel for the survey and validation
Shortlisting the N_F number of factors to be considered for the study.

Step 2: *Design of Q-Set*: Design and Conduct the interview process with N_P numbers of practical and N_A number of academic experts. Prepare the list of all possible Q statements for each of N_F factors. Shortlist the most appropriate N_Q number of Q statements to constitute the Q Set in consultation with all the (N_A and N_P) participants, as shown in Table 2.

Step 3: *Performing Q Sort*: Conduct of on-line survey. A different set of N_{P1} number of practical experts from the case study industry and N_{A1} number of academic experts are invited to rank each Q statement of the Q-Set qualitatively as Agreed, Not agreed and Insignificant and also quantitatively as degree of agreement discretely from the highest +5 to the lowest +1 and the degree of disagreement discretely from the highest -5 to the lowest -1. The insignificant gets the value of zero. Q sorting is done by choosing a software like Q-Method, Q-Sort, Q-Assessor

Step 4: *Formation of distribution grid*: For every Q Sort corresponding to a specific participant, the distribution of Q statements of the Q Set is condensed into a grid, a table showing the distribution of Q statements, using the software. The standard grid format is shown in Figure 1.

Step 5: *Performing Factor Analysis*: The statistical analysis of the ranked Q-Sorts in the grid format in the following steps:

(i) Establishing the strength of the relationship between each pair of Q-Sorts using correlation co-efficient methods, such as Pearson Correlation method, Kendall Rank Correlation Method, Spearman Rank Correlation Method, etc.

(ii) Factor extraction by the Principal component Analysis method

(iii) Factor rotation by a method such as Varimax, Quartmax, Promax, Obliman and Cluster

The analysis using the measure of various significance factor characteristics of the Q-Set is done by the software.

Step 6: Based on the analysis of the results generated by the software, the influential factors that are critical for the digital transformation implementation and the Q statements with the most positive opinion are identified.

3.2 Experimental design

The parameters for the proposed solution procedure are arrived at based on initial trial experiments. They are Number of academic experts N_A = 25, Number of practical experts N_B = 25, Number of survey participants from Academia N_{A1} = 50, Number of survey participants from industry N_{P1} = 10, Number of Factors N_F = 5 (Shown in Table 1) and Number of Q statements in the Q-Set N_Q = 30 (shown in Table 2). Software utilised for the survey and analysis: *Q-Method and* Factor Analysis Tools: Pearson Correlation Coefficient and Varimax Factor Rotation method.

All the participants in the interview and discussion process and the on-line survey are all academic experts in the cadre of associate professors or above or research associates with a minimum of five years' experience in the field of maintenance, reliability, digitization, who are working with engineering institutes affiliated to state and central universities situated in southern part India. Similarly, the industrial experts, in the field of production, maintenance and service activity with more than ten years of experience, both in the supervisory and operational positions, who are working with few SMEs viz., sensor and switch manufacturing plant, tyre and tube manufacturing plant and belt manufacturing plant of a reputed automobile spare parts manufacturing company situated in the southern part of Tamil Nadu state, India, were considered for the present study. The process of online survey, interview and discussions were carried out between July 2020 and Dec 2020. The selected five factors are directly affecting the maintenance management system in the SMEs, and all are interlinked with the implementation of the digital transformations in the MM. The thirty numbers of Q statements related to the digitisation context of MM systems specific to SMEs truly represent the selected five factors. With a detailed introduction to each participant about how to exercise one's opinion about each Q statement qualitatively as in agreement or disagreement or insignificant and to quantitatively rate their opinion on the scale from -5 to +5, each participant is given 30 days to complete his/her survey in the Q-Method link.

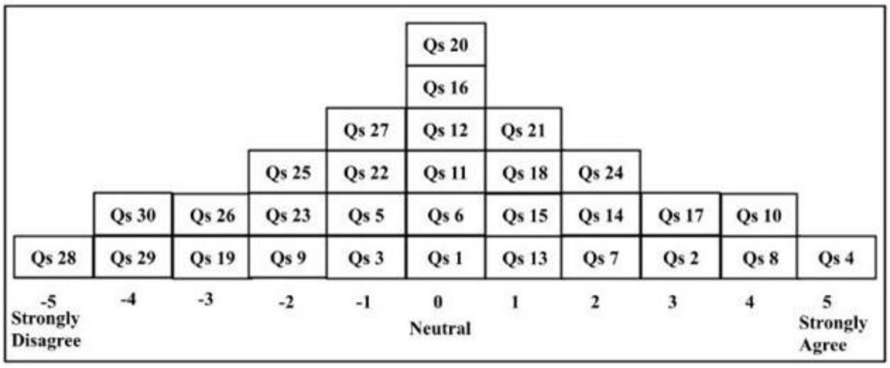

Figure 1 Sample Q sort distribution shown in grid

Table 1 List of factors and associated Q statements

Factors	Influencing Characteristic	Pertinent Q Statements
A	Awareness about digitization	Qs 1, Qs 2.
B	Customer's fulfilment	Qs 3, Qs 4, Qs 5, Qs 6, Qs 7, Qs 8, Qs 9, and Qs 10.
C	Ease of maintenance planning and Scheduling	Qs 11, Qs 12, Qs 13, Qs 14, Qs 15, Qs 16, and Qs 17.
D	Ease of administrations	Qs 18, Qs 19, Qs 20, Qs 21, Qs 22, Qs 23, Qs 24, and Qs 25.
E	Complexity and difficulty	Qs 26, Qs 27, Qs 28, Qs 29, and Qs 30.

Table 2 Q statements

S. No	Q Statements	Factors Scores				
		A	B	C	D	E
Qs 1.	Predictive Maintenance (PdM) is a well-known concept.	-5	-3	0	0	2
Qs 2.	Already I have used autonomous maintenance systems in the industry.	-4	0	3	-2	0
Qs 3.	I wish to know about PdM systems.	1	-3	-1	0	-2
Qs 4.	The PdM process rectifies the consequences of negligence and repairs in everyday life.	3	0	5	2	-1
Qs 5.	I wish to know about maintenance issues in advance.	0	5	-1	0	0
Qs 6.	I wish to learn the tools of PdM	0	0	0	4	2
Qs 7.	Most of the clients prefer PdM in everyday life.	4	-2	2	5	3
Qs 8.	Autonomous and PdM systems can attract more customers.	2	3	4	-1	0
Qs 9.	Autonomous and PdM systems may increase customer satisfaction.	2	0	-2	3	-1
Qs 10.	The autonomous and PdM System creates direct links between manufacturers and customers.	5	4	4	4	-1
Qs 11.	PdM helps to determine the number of workers required for maintenance.	-2	2	0	-2	0
Qs 12.	PdM System helps to give a regular and balanced workload to maintenance workers.	-1	3	0	0	-2
Qs 13.	I agree that the maximum profit is achieved through the PdM Management system.	4	2	5	4	3
Qs 14.	Diagnosing the maintenance problem will help to predict the optimal maintenance planning in the industry.	1	0	2	0	4
Qs 15.	The effectiveness of the machine increased in the PdM management system.	4	0	4	-2	3
Qs 16.	Customers want to minimize waiting time for maintenance work.	0	4	0	-1	5
Qs 17.	Manufacturers want to eliminate unnecessary activities in the industrial maintenance process.	-1	-2	3	-2	2
Qs 18.	Maximum resources spent on the conventional maintenance process.	-2	0	3	4	0
Qs 19.	Faster and less expensive maintenance processes are essential for today's industry.	0	4	-3	-2	4
Qs 20.	The PdM management system will minimize the total maintenance cost of the industry.	2	-2	0	2	-3
Qs 21.	Autonomous maintenance methods will ease the maintenance process.	0	2	4	0	0
Qs 22.	The use of computers and mobile phones plays an important role in the maintenance system.	-2	3	-1	2	-5

S. No	Q Statements	Factors Scores				
		A	B	C	D	E
Qs 23.	Because of knowing in advance, the problems in the maintenance industry can be resolved in minimum time.	2	0	-2	-3	0
Qs 24.	The excessive time required to identify the faults in the conventional maintenance process.	5	1	2	5	2
Qs 25.	The PdM management system minimizes the inventory.	-2	2	-2	2	0
Qs 26.	The complexity is more in the PdM management system.	-2	2	3	3	3
Qs 27.	The workforce required in the PdM management system is minimized.	0	-1	-1	4	1
Qs 28.	In the PdM management system, a large amount of data storage devices are required.	2	2	2	2	-3
Qs 29.	The initial investment cost is more in the PdM system.	1	-3	4	3	-2
Qs 30.	PdM management system needs skilled technicians.	0	-3	-4	-1	-3

4. Results and discussions

Based on the on-line survey and subsequent factor analysis by the Q-Method software, for the selected case study manufacturing plant in the category of SME, which is currently operating without the digitisation and PdM implementation, the result of the factor score of all the thirty Q statements are tabulated in Table 2. The significance of factor characteristics of the Q-sorts resulted out of the PCA and varimax rotation tools used in the statistical analysis is shown in Table 3. The difference in standard error between all the pairs of five factors is computed and shown in Table 4, which is nearly uniform, and this observation validates the correctness and accuracy of the experiment conducted.

Table 3 Characteristics of the Factors

Characteristic	Factors				
	A	B	C	D	E
No. of the loading Q sort	4	3	3	3	4
Composite Reliability	0.9412	0.9231	0.9231	0.9231	0.9412
Standard error of factor score	0.2425	0.2774	0.2774	0.2774	0.2425

Table 4 Standard Error difference between Factors

Factors	A	B	C	D	E
A	-	0.3684	0.3684	0.3684	0.3429
B		-	0.3922	0.3922	0.3684
C			-	0.3923	0.3684
D				-	0.3684

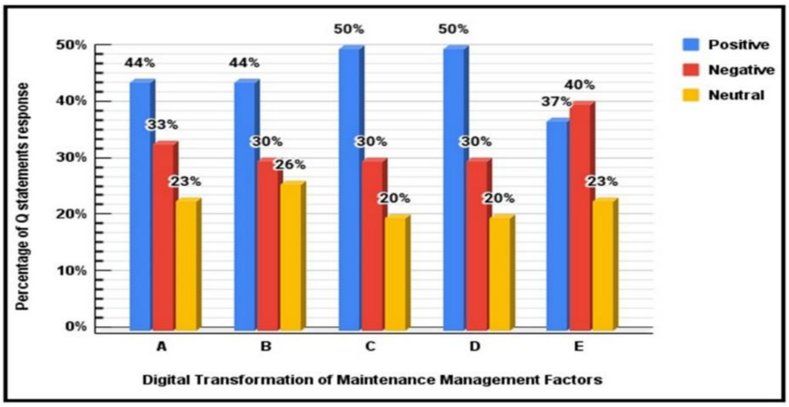

Figure 2 Percentage of experts' responses to the factors related to the digital transformation of MM systems in the SMEs.

The factor wise subjective qualitative opinion of the participants for the Q-Set is shown in Figure 2. The figure exhibits that collectively from both the group of participants, viz industry and academia, every factor considered favours the implementation against all constraints or difficulties that may arise during the implementation. It may be observed in Figure 2 that, among the five Factors, the difference in percentage between the positive and negative response is higher in Factor C and Factor D and hence Factor C and Factor D are more influential compared to the other three Factors.

The quantitative measure of consensus and controversial statements for each of the five factors are displayed in Figure 3. It may be noted that for Factor A, the consensus statements are 3, 4, 7, 8, 9, 10, 13, 14, 15, 20, 23, 24 and 28, controversial statements are 1, 2, 11, 12, 17, 18, 22, 25, 26, and 29, the insignificant statements are 5, 6, 16, 19, 21,27 and 30, and the variation in the degree of consent is wide compared to the degree of controversy. Similar observations may be made for other factors as well in their respective graphs shown in Figure 3. It may be observed in Figure 3, that among the graphs of all the Factors, graphs of Factor C and Factor D exhibit percent of Q statements with positive score and higher positive score values is higher. This implies that the Factor C and Factor D are more influential than the other three Factors. The low degree of insignificance among all Q statements across all factors implies the high level of understanding of the survey and active participation by the truly representative sample of the experts taken.

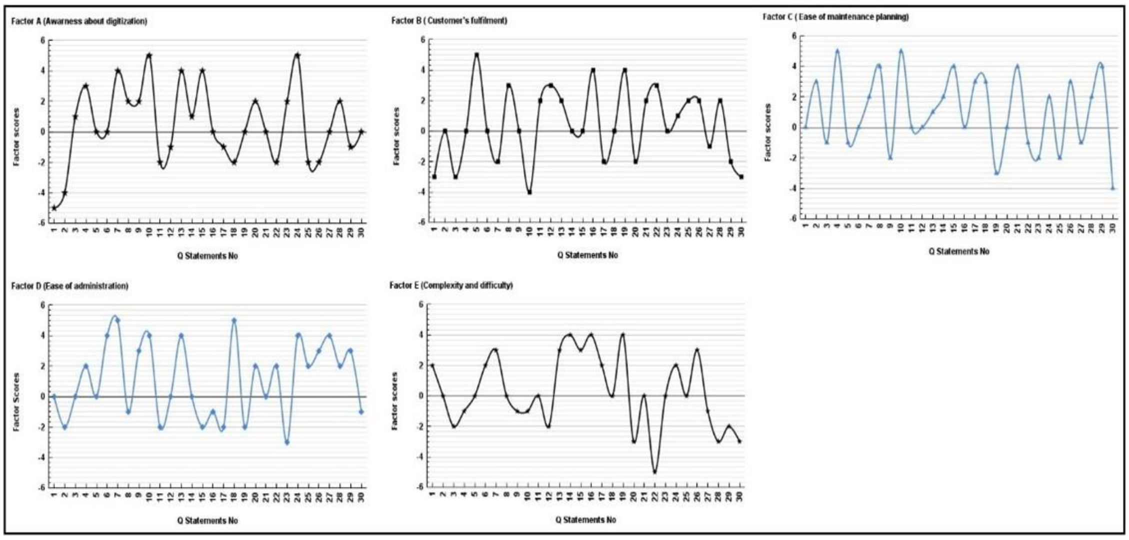

Figure 3 Factor Score of the Q Set

To measure the criticality in influencing the implementation of digitisation, the difference between quantum of consensus and controversy across the five factors is computed and shown in Table 5. It may be noted in Table 5 that this difference is higher for Factor C and Factor D compared to the other three factors. Hence Factor C, the ease of maintenance planning and scheduling and Factor D, maintenance administrations are more influential than the other three factors. The highest and lowest rated Q statements in each factor are shown in Table 6.

Table 5 Measure of criticality of Factors

Factors	A	B	C	D	E
Positive Response of Q statements (Pfs)	2.84615	2.8333	3.13333	3.2	2.875
Negative Response of Q statements (Nfs)	2.2	2.44444	1.81818	1.875	2.1882
Difference (Δfs =Pfs-Nfs)	0.64615	0.38888	1.3151	1.325	0.69318

Table 6 Highest and Lowest rated statements of each factor

Factors	Highest rated	Lowest rated
A	The autonomous and PdM System creates direct links between manufacturers and customers.	Predictive Maintenance (PdM) is a well-known concept.
B	I wish to know about maintenance issues in advance.	The initial investment cost is more in the PdM system.
C	I agree that the maximum profit is achieved through the PdM Management system.	PdM management system needs skilled technicians.
D	The excessive time required to identify the faults in the conventional maintenance process.	Because of knowing in advance, the problems in the maintenance industry can be resolved in minimum time.
E	Customers want to minimize waiting time for maintenance work.	The use of computers and mobile phones plays an important role in the maintenance system.

Hence the outcome of this research work, through the quantitative and qualitative factor analysis of the real time subjectivities or opinions of the industrial and academic experts in the field of reliability and maintenance has proved that Factor C and Factor D are the most influencing/critical factors for the successful digitization of maintenance management system of a SME.

The outcome of this research work, that is, factor analysis for the digital implementation in smart maintenance management systems is also compared with that of two similar research works reported in the literature, viz. The study of Bartlett and DeWeese (2015) was done on the factor analysis in the field of Human Resource Development through the Q method analysis. Another study by Rahma et al. (2020) explains the factor analysis by the same research approach in the field of Educational Development. The factor characteristics, the measures of accuracy of identifying the most influential factors, namely composite reliability and standard error of factor score, are compared among the above-mentioned three research works and presented in Table 7.

Table 7 Comparison of Factor Characteristics

Characteristics	Research Work	Factors				
		A	B	C	D	E
Composite Reliability	Bartlett and DeWeese (2015)	0.9410	0.8890	0.8000	0.8000	0.8000
	Rahma et al. (2020)	0.9230	0.8890	0.9520	0.8990	0.8890
	Proposed in this work	**0.9412**	**0.9231**	**0.9231**	**0.9231**	**0.9412**
Standard Error of Factor scores	Bartlett and DeWeese (2015)	0.2430	0.3330	0.4470	0.4470	0.4470
	Rahma et al. 2020	0.2777	0.3330	0.2190	0.3330	0.3330
	Proposed in this work	**0.2425**	**0.2774**	**0.2774**	**0.2774**	**0.2425**

The work presented in this research, and the two above-mentioned work reported in the literature, have similarities in terms of the number of factors taken (five), the framework of Q-methodology applied, and rating of factors (from -5 to +5). However, the size of Q Set in this work 30 as against 34 (in Rahma et al., 2020) and 53 (in Bartlett, & De Weese, 2015). It may be observed that the composite reliability measured in the methodology devised in this research work, with respect to the four factors viz., A, B, D and E, is higher than that of the other two methodologies reported in the above-said literature. Similarly, the measure of standard errors with the methodology devised in this work concerning the same four factors is lesser than that of the methodologies reported in the literature, which may be attributed to the above-mentioned similarities observed among the above-said three studies, and also the number of defining variables used in the same varimax rotation method used. However, for factor C, which is about ‘Ease of maintenance planning and scheduling’, the standard error is more, and composite reliability is less than the other two reported methodologies. This implies that the survey participants have diverse and inconsistent opinions or responses to the Q statements pertaining to this factor compared to the other four factors. Its accuracy can also be improved by imparting additional training and education to the participants on this particular factor. However, the accuracy of the proposed methodology is found to be better than that of the other two reported in the literature in terms of consistency of accuracy measures, as can be seen in Table 7.

5. Conclusion

This research work focuses on digital transformation in maintenance management systems in SMEs and implementation of predictive maintenance schemes, which would be based on real-time machine failure, repair and maintenance data. Such digital transformations will result in a huge improvement in maintenance activities and thereby increase SMEs' overall efficiency and sustained growth. The objective of this work is to identify the most critical factors that will influence the implementation of digitisation of MM system. The Q methodology that is being widely utilised in medicine was applied in this work in the maintenance system in the field of manufacturing-specific in SMEs environment. A solution procedure conforming to the Q methodology framework was developed and applied to a specific segment of SMEs. Experiments were conducted by selecting a few case study industries, parameters for the study like a number of relevant Factors, Q statements, choosing the participants for the survey, software for the survey and tools of factor analysis.

The study and the results of the experiments revealed the two most critical factors, namely the ease of maintenance planning and scheduling and ease of maintenance administration, have been identified to influence the implementation of digitisation. The solution methodology has been validated by conducting the experiments with similar SMEs having similar operation and maintenance working environments in a different location in the southern part of India and comparing the results obtained.

It may be observed from this study that, the success of Q Methodology framework largely depends on how correctly collect the participants viewpoints/perceptions and how accurately analysing them for drawing the conclusions. And so the limitation of the proposed methodology is in the formulation of different Q statements (so that the concerned participants understand them without ambiguity), selection of factors, relevant participants and so on, depending on the type and nature of the maintenance environment that prevails in different manufacturing SMEs. Hence, a wide range of design layouts for the proposed methodology seems to be unavoidable to cater for the needs of different SMEs. Also, the amount of effort and time in testing and validating for each different design will be very high. These challenges pave the scope for future research in this area. Hence, the immediate future focus would be classifying the SMEs based on their similarity with respect to the maintenance activities in to groups and constructing the framework/strategy for the Q method for each group of SMEs. Another potential scope for further research would be evolving a similar solution methodology for large-scale industries, where each industry will exhibit a strikingly different maintenance environment. Combined or integrated factor critical analysis using other techniques like Fuzzy Analytical Hierarchy Process and Fuzzy TOPSIS approach may also be thrashed out in future research

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