PERFORMANCE MEASUREMENT SYSTEMS IN ENGINEERING ORGANISATIONS

C.F. Swart[1*] & P.N. Zincume[1]

ARTICLE INFO

Article details
Presented at the 34th annual conference of the Southern African Institute for Industrial Engineering, held from 14 to 16 October 2024 in Vanderbijlpark, South Africa

Available online 29 Nov 2024

Contact details
* Corresponding author
katiefswart@gmail.com

Author affiliations
1 Department of Industrial Engineering, Stellenbosch University, South Africa

ORCID® identifiers
C.F. Swart
https://orcid.org/0009-0005-5933-2346

P.N. Zincume
https://orcid.org/0000-0001-6041-8167

DOI
http://dx.doi.org//10.7166/35-3-3083

ABSTRACT

Performance measurement systems (PMSs) are vital for quantifying organisational efficiency and effectiveness, empowering decision-makers to manage processes for operational, and strategic realisation. Despite extensive research, difficulties with implementation persist, impeding institutionalisation. While the factors influencing PMS implementation have been studied, research specific to engineering organisations is limited. This paper employs a bibliometric analysis to confirm PMSs' relevance in modern organisational contexts and explores a metric, a quantitative tool, for equipment performance evaluation. Twenty-one prevalent implementation factors, categorised under the '6Ms' of production, are identified from the literature. These factors are substantiated for the modern engineering domain using detrimental implementation factors unearthed in Company X, a South African dairy product producer. The resolution of these factors, particularly related to data in Company X, is proposed through a Microsoft Excel workbook facilitating overall equipment effectiveness (OEE) calculations. This validated and refined solution enhances PMS effectiveness, converting data into actionable information for management benefits.

OPSOMMING

Prestasiemetingstelsels (PMS'e) is noodsaaklik vir die kwantifisering van organisatoriese doeltreffendheid en effektiwiteit, wat besluitnemers bemagtig om prosesse vir operasionele en strategiese realisering te bestuur. Ten spyte van uitgebreide navorsing duur implementeringsuitdagings voort, wat institusionalisering belemmer. Terwyl die faktore wat PMS-implementering beïnvloed, bestudeer is, is navorsing spesifiek tot ingenieursorganisasies beperk. Hierdie artikel gebruik 'n bibliometriese analise om PMS'e se relevansie in moderne organisatoriese kontekste te bevestig en ondersoek 'n maatstaf, 'n kwantitatiewe hulpmiddel, vir toerustingprestasie-evaluering. Een-en-twintig algemene implementeringsfaktore, gekategoriseer onder die '6Ms' van produksie, word uit die literatuur geïdentifiseer. Hierdie faktore word vir die moderne ingenieursdomein gestaaf deur gebruik te maak van nadelige implementeringsfaktore wat in Maatskappy X, 'n Suid-Afrikaanse suiwelprodukprodusent, opgediep is. Die oplossing van hierdie faktore, veral wat verband hou met data in Maatskappy X, word voorgestel deur 'n Microsoft Excel-werkboek wat berekeninge van algehele toerustingdoeltreffendheid (OEE) vergemaklik. Hierdie bekragtigde en verfynde oplossing verbeter PMS-doeltreffendheid en omskep data in uitvoerbare inligting vir bestuursvoordele

1. INTRODUCTION

Industrial engineering involves the pursuit of an optimal balance by considering trade-offs between time, cost, and performance across entire organisations. Industrial engineers specialise in analysing the functionality of systems and identifying areas where improvements may be implemented. The optimisation of these systems aims to reduce waste, enhance quality, and increase productivity to ensure more efficient and effective operations. To achieve these objectives, *performance measurement systems* (PMSs) are employed [1]. These systems allow organisations to identify their current market positions and to clarify their goals in order to achieve more streamlined operations, resulting in an essential competitive edge in today's dynamic business environment [2].

A PMS may be formally defined as the set of metrics used to quantify both the efficiency and the effectiveness of actions. The effectiveness of an action is quantified by the degree to which customer requirements are met, whereas the efficiency of an action denotes how economically the organisation used its resources to achieve a predetermined level of customer satisfaction [3]. Engineering organisations, like any other organisation, need to select PMSs that align seamlessly with their specific operational context. This alignment is crucial to ensure that *performance measurement* (PM) and control mechanisms are in harmony with the organisation's defined strategic objectives [2].

Many different PMSs have been developed over the years, each focusing on improving performance in distinct areas of organisations. The most widely used PMS to date is the *balanced scorecard* (BSC). Despite extensive research on PMSs, the majority of previously developed PMSs are static and unresponsive to changes in the organisation in which they operate [4]. While there have been decades of research in the field of PM, significantly less research is dedicated to PMSs in engineering organisations. It has been highlighted that there is a need to focus research on extending operations and processes within engineering [5].

A PMS comprises four processes, namely design, implementation, usage, and maintenance [6]. Each of these processes leads to factors that contribute to the success or failure of a PMS. Factors contributing to system failure are referred to as *barriers*, while those contributing to success are referred to as *enablers* [7]. Among the four processes, the literature suggests that the implementation of a PMS is of the utmost importance. Implementation should be a continuous and iterative improvement process, involving the re-evaluation and improvement of the design's implementation. This may take the form of a reviewed process approach, providing opportunities for organisational improvement [4].

This paper confirms the applicability of PMSs in modern organisations through a maturity assessment in Section 2. In Section 3, the role of PMSs in all organisations is discussed, with a focus on the overall equipment effectiveness (OEE) metric for engineering organisations. Factors found in the literature to affect PMS implementation are categorised under the '6Ms' of production. An AS-IS analysis in Section 4 examines Company X's PMS, identifying the barriers and enablers. In Section 5, the OEE metric is proposed to address significant barriers in Company X, with the validation and revision of the solution detailed in Section 6. Finally, Section 7 discusses the contributions of this paper and offers recommendations.

2. MATURITY OF PM RESEARCH FIELD

2.1. Performance measurement's evolution

The modern PM field is a consequence of two successive major growth phases. The first phase, sparked by the first industrial revolution in Europe and America, focused on cost accounting and productivity. In contrast, the second phase began after the globalisation of trade and the emergence of the world economy, which created a more competitive market with demanding customers. Consequently, the focus of PM shifted towards strategy based on quality, time, cost, flexibility, and customer satisfaction. During this second phase, researchers criticised the traditional financial measures and deemed them inappropriate for measuring business performance. A PM crisis emerged owing to the shortcomings of these traditional measures, sparking a revolution in existing PMSs that transformed them into more integrated [8].

Research focused on PMSs has grown in popularity [8], as dated studies are losing their relevance owing to the dynamics of modern business [5]. The collection and analysis of data, the core of a PMS, has been championed by the proliferation of modern technological innovations [9]. The *Fourth Industrial Revolution* (4IR), otherwise known as Industry 4.0, is at the heart of these advancements. The 4IR aims to integrate additive manufacturing, augmented reality, autonomous robots, big data and analytics, cloud computing, cybersecurity, horizontal and vertical system integration, the industrial *Internet of Things* (IoT), and simulation into all organisations. Research on the adaptations made to PMSs to align with the 4IR is scarce [9], while the benefits of these technologies are extensively highlighted [10]. This presents an opportunity for the design new PM tools, frameworks, and systems in a highly automated, integrated, and fully digitalised environment [11].

2.2. Bibliometric analysis

The maturity of the PMS research field was evaluated on 15 May 2023 by means of a bibliometric analysis, using the Scopus database. The database was searched on all information up to the search date, focusing on article titles containing the 'performance measurement system' keywords. Only journal articles were considered, and 1,584 documents constituted the final research sample. The sample was downloaded and analysed using VOSviewer to identify and comprehend the trends.

The final research sample analysis was achieved on the basis of the articles' temporal (Section 2.2.1) and author nationality (Section 2.2.2) attributes. Bibliometric analyses serve to complement traditional literature reviews by using statistical methods to analyse substantial volumes of scientific data and by identifying trends in the body of the literature.

2.2.1. Temporal analysis

Temporal analysis aids the examination of publication years to gain insight into the research's evolution. The first publication in the sample research was in 1960 – the sole publication for that year. Thereafter, each year saw multiple publications on the subject. The year 2019 showed a significant peak with 88 publications, making it a pivotal year in PMS research. Figure 1 illustrates the annual number of journals published from 1960 to 2023; the distribution in the graph reveals several peaks and valleys. Despite noticeable fluctuations, an underlying upward trend is evident, indicated by the exponential trend line on the graph. This trend suggests that PMSs are progressively gaining popularity in the literature. That progression accounts for the relevance that PMSs have in modern organisations, and the research's continuous growth shows the need for PMSs to adapt to changing business and technology dynamics.

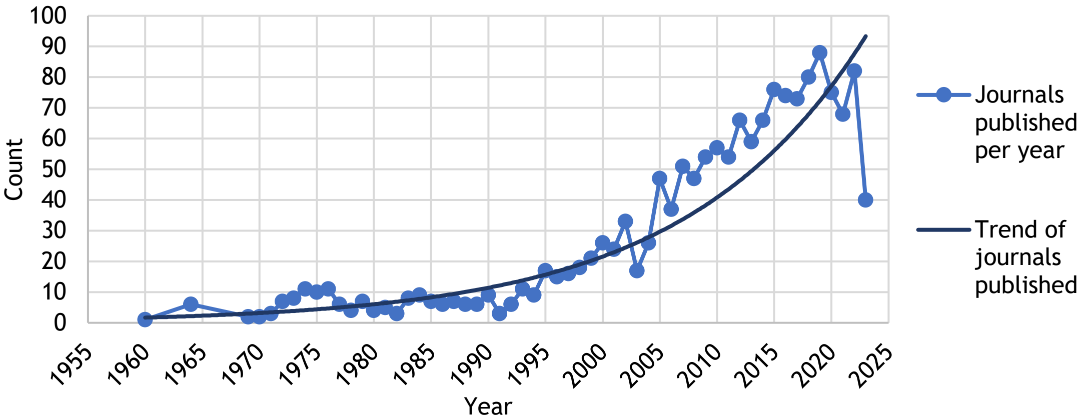

Figure 1: Annual number of journals published

2.2.2. Author nationality analysis

Author nationalities are investigated to understand the research contributions from different countries and continents. To maintain a manageable scope, a restriction of 25 countries per document was implemented. In addition, only countries with a minimum of five documents, and without imposing a minimum citation threshold, were included in the analysis. Consequently, 43 countries were identified from the initial pool of 129.

Out of the 43 identified countries, 40 displayed interconnections, forming a network, as shown in Figure 2. This network comprised seven distinct clusters. Overall, the *United States* (US) features the largest circle in the network, encompassing 309 documents. Notably, the US circle is considerably larger than China, the second most prominent contributor with 159 documents. In fact, the number of documents published by authors of Chinese origin accounts for only 51.5% of the articles authored by their US counterparts. The circle representing the *United Kingdom* (UK) is about the size of China, featuring 152 documents.

When examining these documentary contributions on a continental basis, Europe is at the forefront with 37.85%, closely followed by Asia with 30.43%. Notably, a significant portion of the research is concentrated in more developed regions such as Europe and North America. These developed first-world countries' research aids the development of PMSs, enabling them to adapt to the modern business environment using 4IR tools. While Asia contributes substantially to the research, it shows variations in the level of development among its countries. Much of Asia's research originates from developing nations such as China and India, where production could benefit from using PMS; and this supports the idea that PMSs are valuable in the production and manufacturing environment today. Africa contributes the fewest articles among the continents involved in PMS research. Overall, a significant amount of literature is being generated in more than 40 different countries worldwide, confirming the global interest in PMSs.

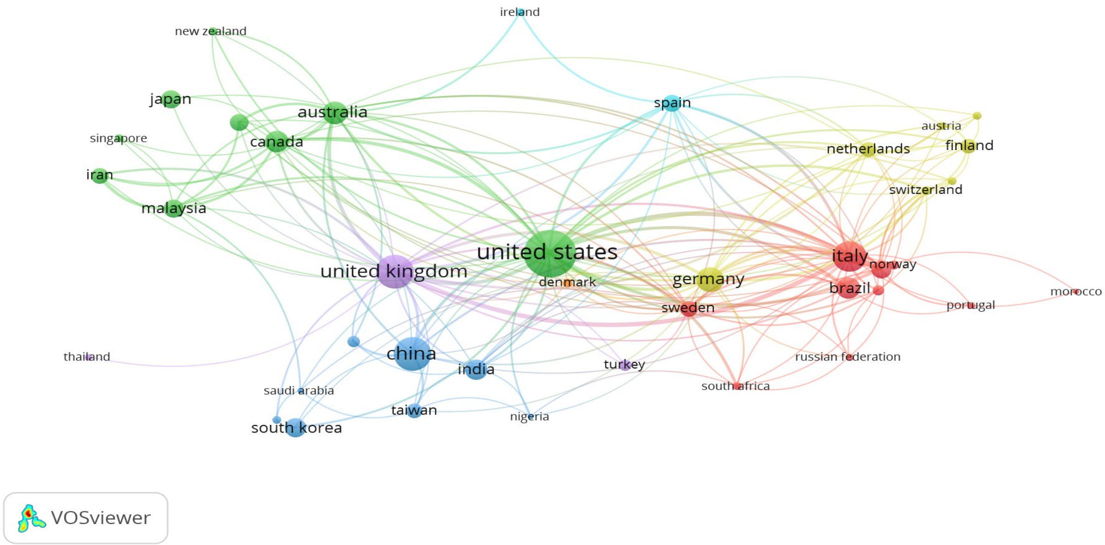

Figure 2: Authors' nationality network

3. LITERATURE REVIEW

This section briefly explores the purpose of PMSs in all organisations (Section 3.1), followed by an outline of the *overall equipment effectiveness* (OEE) metric that is applicable to engineering organisations (Section 3.2); and 21 factors from the literature that affect the successful implementation of PMSs in engineering organisations are listed (Section 3.3).

3.1. Performance measurement system

PMSs have evolved through the years, transitioning from originally providing rudimentary accounting-related information to offering comprehensive information covering both financial and non-financial aspects [12]. As a consequence, they have emerged as one of the most crucial decision-making instruments for managers, introducing a scientific approach into the decision-making process. This shift alters the focus of management from depending on experiences and judgement to being based on information and knowledge [13]. The information derived from a PMS empowers decision-makers to oversee and regulate processes, contributing to the realisation of business and operational strategies. Consequently, PMSs play a pivotal role in the effective and efficient management of any organisation [14].

3.2. Overall equipment effectiveness

There is an abundance of research into the implementation and use of PMSs in engineering organisations. As defined by the Engineering Council of South Africa (ECSA) [15], engineering organisations include those dealing with various technical components on different levels. These technical components entail information management, risk analysis and evaluation, supply chain management, decision analysis, resource optimisation, modelling and simulation, and statistical analysis [15].

Technical equipment plays a pivotal role in a manufacturing system, directly influencing product quality, cost, and overall plant productivity [16]. Nakajima's [17] OEE metric stands as the gold standard for measuring manufacturing productivity, and aims to identify the percentage of truly productive manufacturing time [18]. This quantitative tool evaluates equipment performance relative to its theoretical maximum capacity, which includes only scheduled run times. An OEE score of 100% theoretically signifies flawless product quality, peak speed (performance), and continuous operations with minimal interruptions (availability) [19]. Measuring OEE is a best practice for systematically improving systems, and offers numerous advantages such as avoiding cognitive biases in decision-making, focusing on critical success parameters, revealing chronic losses hidden by machine defects, and reducing production losses to achieve defect-free output. This metric is the single best way to identify losses, benchmark progress, and improve equipment productivity, ultimately eliminating waste [20].

OEE is the product of three key components: *(1) availability, (2) performance, and (3) quality*. OEE (%) is defined as

$$\boldsymbol{OEE}\ [\%] = \boldsymbol{Availability} \times \boldsymbol{Performance} \times \boldsymbol{Quality} \tag{1}$$

Availability includes both planned interruptions such as setups, planned maintenance, cleaning, and quality inspection, and unplanned stoppages because of issues such as breakdowns [20]. The formula for availability is defined as

$$\boldsymbol{Availability}\ [\%] = \frac{\boldsymbol{Actual\ running\ time}}{\boldsymbol{Total\ planned\ running\ time}} \tag{2}$$

where actual running time is

$$\boldsymbol{Actual\ running\ time} = \boldsymbol{Total\ planned\ running\ time} - \boldsymbol{Total\ stoppages} \tag{3}$$

Performance is when processing operates below full capacity, which may result from factors such as environmental conditions, operator performance, equipment availability, and maintenance issues [20]. The formula for evaluating equipment performance is

$$\boldsymbol{Performance}\ [\%] = \frac{\boldsymbol{Standard\ time\ recovered}}{\boldsymbol{Actual\ running\ time}} \tag{4}$$

where the standard recovery time is

$$\boldsymbol{Standard\ time\ recovered} = \boldsymbol{Production\ mass} \times \boldsymbol{Throughput} \tag{5}$$

Quality pertains to flawed products that reduce overall yield, often owing to factors such as operator errors, incorrect settings, or improper batch changeover processes [20]. Equipment quality is evaluated with

$$\boldsymbol{Quality}\ [\%] = \frac{\boldsymbol{Total\ finished\ goods\ produced}}{\boldsymbol{Total\ produced}} \tag{6}$$

where the total produced is

$$\boldsymbol{Total\ produced} = \boldsymbol{Total\ finshed\ goods\ produced} + \boldsymbol{Defective\ produce} \tag{7}$$

3.3. Factors affecting the implementation of a PMS in engineering organisations

The interaction between a PMS and its environment exposes the system to various influential factors, both barriers and enablers. The literature offers extensive insights into the design of various measurement systems, yet organisations frequently struggle to implement and fully use these systems effectively [21].

Notably, the failure rate in the implementation and use of PMSs stands at about 70%, impeding organisations from harnessing the potential benefits of this management tool [22]. The factors influencing the successful implementation and use of a PMS in engineering organisations may be categorised according to the '6Ms' of production.

These categories form the basis of the following six customised categories:

1. Mother Nature (culture): relates to the culture and environment of the organisation where the PMS is implemented.
2. Method (system): concerns the methods used for PMS implementation and use.
3. Material (data): relates to the data and information management.
4. Machines (technology): is focused on the resources and tools required for PMS implementation and use.
5. Man (people): centres on the use of the PMS by people.
6. Measurement (indicators): relates to the performance measures and indicators used in the PMS.

Twenty-one identified factors from the literature are illustrated in Figure 3, an Ishikawa (fishbone) diagram that offers a comprehensive view of the factors and their categorisation. This representation aligns the six major colour-coded categories, based on the 6Ms, along the primary spine of the fish, with sub-factors branching out as ribs.

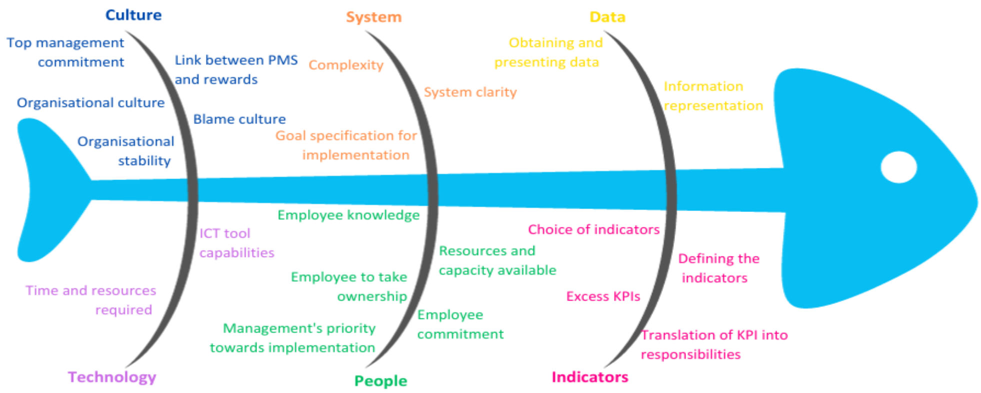

Figure 3: Ishikawa diagram of identified factors affecting PMS implementation and usage

4. CASE STUDY: COMPANY X AS-IS ANALYSIS

An AS-IS analysis based on data gathered from a site visit to Company X served as a foundation for developing a specialised solution effectively to improve the current PMS in use. The performance measurement in the company was comprehensively analysed, to pinpoint factors, both barriers and enablers, contributing to the success of the PMS in the company. In addition, a comparison was made between the identified factors in Company X and those found in the literature to validate their applicability to real-world engineering organisations.

4.1. Performance measurement in Company X

To maintain its market share and competitive advantage in the South African dairy products market, Company X is committed to continual improvement, particularly in its packaging facility. This facility is crucial for swift product delivery and maintaining promised quality levels. Ensuring the quality and integrity of the packaging for dairy products is crucial, as subpar packaging potentially leads to contamination and may render the product and production process futile. In the packaging facility there are four processing lines, each serving distinct purposes. Of the four lines, Line 1 and Line 4 are of particular significance, as they handle the majority of the processing volume, and therefore were the focus of this investigation.

While performance was being measured on these lines, there were pre-existing problems that undermined these measurements.

The packaging facility employs a performance measurement system (PMS) via a performance board, highlighting key metrics in four categories: speed, quality, cost, and safety/morale. Each category uses bar graphs to display key performance indicators (KPIs) against constant benchmarks, simplifying daily and weekly performance comparisons. The manager updates the board daily before morning meetings, reflecting the previous day's performance, and resets it weekly. The board is prominently displayed, benefiting both management and employees.

- **Speed**: assesses adherence to the production plan for all four lines.
- **Quality**: detects foreign bodies, and represents the percentage of pallets on hold and foreign microorganisms in Line 4.
- **Cost**: quantifies yields and losses, focusing on offcuts in Line 1 and waste in Line 4, and graphs the percentage of overweight products in both lines.
- **Safety/morale**: evaluates safety incidents and measures morale through absenteeism rates.

4.2. Factors affecting successful implementation of the PMS in Company X

To devise implementation strategies that adeptly mitigate and anticipate the resultant effects of these factors, the factors affecting system success had to be accurately identified [23]. This identification would enable the validation of factors in the literature.

4.2.1. Identified enablers

Table 1 presents the enablers that notably contributed to the successful implementation and use of the PMS in Company X. These enablers are categorised by the established categories based on the 6Ms of production, each accompanied by a brief description of its contribution to the system's success.

Table 1: Identified enablers

Enabler	Factor category	Enabler description
Top management commitment	Culture (Mother Nature)	Managers prioritise facility performance, using agile problem-solving and fostering a performance-oriented culture. They daily examine factors preventing optimal performance.
Refinement of indictors	Indicators (measurement)	Recent change in management led to a review of the indicators used, resulting in the retention of only insightful indicators.
Employee commitment	People (man)	Employees are motivated to strive for the recognition of 'line of the day' by managers. Exceptional performance is also rewarded.
System clarity	System (method)	The PMS's purpose is clearly communicated, focusing on continuous improvement and maximum throughput, dispelling misconceptions about non-performance punishment.
Continuous maintenance	Technology (machines)	Maintenance staff are consistently on duty, conducting repairs and preventative maintenance as needed and minimising system breakdowns, which positively impacts the accuracy of PMS outputs.
Translation of KPIs into responsibilities	Indicators (measurement)	The PMS that is used contains actions that are required to address difficulties in each section that cause the failure to attain benchmarks. These actions are recorded and the responsibility is assigned to a staff member.
Organisational readiness for PM	Culture (Mother Nature)	The facility supervisor adapts to current capabilities, introducing changes incrementally and encouraging employee engagement with the PMS, fostering autonomy.

4.2.2. Identified barriers

Table 2 provides an overview of the barriers that hinder the successful implementation and use of the PMS in Company X. These barriers are categorised according to the 6Ms of production, and each barrier is accompanied by a brief description outlining its adverse effects on the PMS.

Table 2: Identified barriers

Barriers	Factor category	Barrier description
Management style	Culture (Mother Nature)	The production manager and production supervisor have different managerial approaches, which potentially leads to confusion among employees.
Quality of performance data	Data (material)	Inconsistent KPI measurement methods (automated vs manual) can result in inaccurate data, potentially exaggerating performance and leading to misinterpretation.
Obtaining and presenting data	Data (material)	KPI measurement difficulties and manual data extraction can cause delays and inaccuracies, preventing the full use of the available data.
Information representation	Data (material)	While KPIs drive improvement, they may not align directly with organisational objectives, limiting their decision-making utility.
Resources allocated for implementation	Technology (machines)	Inadequate customisation and resource allocation of an Excel tool to translate KPIs into usable information hinders its effective implementation.

A substantial portion of the identified factors at Company X align with the 21 factors identified in the literature, which underscores the applicability of these factors to modern engineering organisations such as Company X. Company X benefits from enablers in five of the six factor categories: culture (Mother Nature), method, machines, man, and measurement. Despite having seven enablers, the main obstacle lies in the data (material) category, causing three out of the five barriers. This highlights the critical need to focus on the data underpinning the PMS. Ineffective translation of data into valuable information renders the data extraction process counterproductive, costly, and resource intensive. In addition, there is a lack of tools to convert measured KPIs into informative metrics for management. Addressing these problems, particularly for Lines 1 and 4, would significantly enhance performance measurement in Company X.

5. PROPOSED SOLUTION

The primary barrier to successfully implementing Company X's PMS was data-related issues. To address this, we proposed leveraging the OEE metric, a crucial tool for translating KPIs into actionable information, aiding management in decision-making, identifying issues, and formulating solutions. Optimising OEE could boost capacity, reduce costs, enhance efficiency, and improve product quality.

5.1. Translation of data

Meetings with key personnel were used collectively to identify a solution – the OEE metric – that would align with Company X's objectives and would be viable for implementation. The OEE calculation offered a broad solution that could be used to pinpoint specific data issues. OEE would provide management with an all-encompassing insight into the packaging facility's operations, thus adding value to Company X. This comprehensive insight would enable the identification of processing issues, including data-related problems, and would prioritise their resolution. Specifically, performing OEE calculations for both problematic lines (Lines 1 and 4) and the entire packaging facility was vital to ensure precise measurements, particularly for these high-activity lines. These lines are pivotal in the facility's operations, and their performance must be accurately assessed for management to reap its advantages.

5.2. Template A

Using Microsoft Excel as a tool, Template A was tailored to streamline the OEE calculation process in order to rectify the data related issues. Microsoft Excel proved to be a fitting choice for Company X, as it offered easy implementation, user-friendly navigation, and straightforward maintenance, regardless of the user's competence. Template A's primary objective was to translate KPIs (data) measured over a five-day workweek, featuring 7.5 hours of processing daily for both shifts 1 and 2 on Lines 1 and 4, into actionable metrics, where Lines 1 and 4 both process an array of products that vary per week. 'Shift 1' denotes the day shift, and 'shift 2' represents the night shift. The measured metrics for each processing line were categorised by availability, quality, and performance, and collectively aided the calculation of the factory's OEE. Template A consisted of four distinct sheets, each serving a specific role in the OEE calculation: *(1) weekly standard time recovery calc., (2) Line 1, (3) Line 4, and (4) factory OEE*.

Template A operated on a weekly basis, managing data pertinent to each specific week, denoted as week 'n'. This weekly approach aligned with Company X's needs, as daily updates would have been impractical and would have wasted time, while monthly reviews could have allowed issues to fester before they were addressed. At the start of each week, the weekly standard time recovery calc. sheet was cleared, and new data was input for the subsequent week (n+1). In contrast, the Line 1, Line 4, and factory OEE sheets retained data logs for each week, organised in columns across the sheets, covering weeks 1 to 52.

5.2.1. Template A configuration

To adapt Template A for weekly use at Company X, initial once-off user inputs were required to tailor the template to their specific facility. These inputs only needed adjustments when there were changes in the facility's overall capabilities, such as new weekly processing hours. Once these sheets had been configured, based on the provided inputs, Template A was ready for users to input weekly variable processing data, which would then be transformed into useful metrics for management. In Template A, only the first three sheets (*weekly standard time recovery calc., Line 1*, and *Line 4*) required initial inputs, while the last sheet (*factory OEE)* did not. The setup of Template A comprised the following once-off steps:

Configuring *weekly standard time recovery calc.* sheet: To set up this sheet, document the products processed on both Lines 1 and 4. This includes listing product codes, providing brief descriptions for each product, and specifying the throughput (kg/hr) for each product processed on each line. The recorded throughput for each product should reflect the maximum bottleneck throughput for that specific product.

Configuring *Line 1* and *Line 4* sheets similarly: To configure these sheets, input the planned running time (in minutes) per shift for each sheet respectively, where each sheet pertains to respective a line. This represents the duration that one shift is scheduled to operate during a typical five-day week.

5.2.2. How Template A functions

After configuring Template A, users need to input variable processing data to enable the template to calculate the weekly factory OEE for the facility. This process starts by populating the *weekly standard time recovery calc.* sheet with data for week *n*. This data is then referenced, displayed, and used by both *Line 1* and *Line 4* sheets to calculate the availability, performance, quality, and OEE of the respective lines. Finally, the *factory OEE* sheet refers to, displays, and uses the mentioned line metrics to calculate the packaging facility's overall availability, performance, quality, and OEE.

5.2.2.1 Operation of the weekly standard time recovery calc. sheet

This is the only sheet that needs to be cleared weekly. The cells associated with the weekly input are colour-coded blue for clarity and improved usability. Users are required to input the total production mass (in kilograms) for each product processed per shift on Lines 1 and 4 respectively during week *n*. This input includes only the production mass that meets specifications; this input is also referred to as the total finished goods produced. The sheet is then prompted by this input to calculate automatically the total production mass per shift for week *n*. By employing the standard time recovered (in hours) formula, this sheet automatically calculates this value for each line per shift for each product where the total production mass was input, and the total standard time recovered per shift. These two calculations are performed for the given week *n*.

5.2.2.2 Operation of the Line 1 and Line 4 sheets

The Line 1 and Line 4 sheets in Template A have identical layouts, functions, user inputs, and calculations, but each uses data that is specific to its respective line. Each sheet is divided into three sections: availability, performance, and quality. Cells requiring user input are colour-coded in blue for clarity.

- Availability: Users input total stoppages (in minutes) for shifts 1 and 2, adding only stoppages lasting more than three minutes. The sheet calculates availability (%) using the total stoppages and planned running time. The actual running time (hours) is determined to calculate overall line availability.
- Performance: Actual running time is converted to hours, and the standard time recovered (hours) is displayed. Performance (%) is calculated for shifts 1 and 2, and overall performance is determined by summing these inputs.
- Quality: The total finished goods produced (kg) per shift is displayed. Users input defective parts (kg) per shift, including B grade mass and quality control rejects. Quality (%) is calculated for each shift, and overall line quality is determined using these inputs.

Both sheets automatically calculate line OEE using availability, performance, and quality for week n. The layout of the Line 1 sheet covers weeks 1 to 5. The Line 4 sheet has a similar layout.

5.2.2.3 Operation of the factory OEE sheet

The final sheet in Template A consolidates data from both Line 1 and Line 4, displaying availability, performance, quality, and OEE data outputs for the weeks when both *Line 1* and *Line 4* sheets have been populated. By using these metrics as inputs, this sheet is designed to calculate the factory-wide availability, performance, quality, and OEE through an average of Lines 1 and 4 outputs. This consolidated view streamlines the process of comparing and fault-finding for management.

6. VALIDATION AND SOLUTION REVISION

To validate Template A, the proposed solution being introduced to address a significant issue identified during the AS-IS analysis of Company X (problem identification) was required. The resolution of these problems in Template A led to the creation of the revised template, referred to as Template B.

6.1. Validation by Company X

To validate the proposed solution, Template A, and to integrate revisions based on the problems identified by Company X, real-world processing data from Company X's packaging facility was input to test the functionality of the workbook and to identify problems. The data input and functionality test was undertaken by the manager in charge of using the template. The revised solution, known as Template B, was a refined, problem-free, and streamlined OEE calculation aid.

The production supervisor of Company X identified and reported the following problems, which were considered and addressed when developing the revised solution:

1. The *weekly standard time recovery calc*. sheet, which was cleared and updated weekly, removed the previous week's data upon updating and inserted new data into the calculations for both week *n* and week *n+1*. This resulted in identical calculations in the next three sheets for week *n* and week *n+1*.
2. The layout of the *weekly standard time recovery calc*. sheet was suboptimal.
3. After completing the factory OEE calculations, there was no tool to visualise the metrics.
4. Overall, some sheets appeared visually cluttered.

The first issue pertained to a referencing problem related to the *weekly standard time recovery calc*. sheet, which was referenced in both *Line 1* and *Line 4* sheets for all *n* weeks. This reference problem resulted in data from the current week overwriting and replacing the data from all previous weeks, causing problems in the *Line 1* and *Line 4* sheets. It was essential to highlight this as the most pressing issue, as it directly affected the functionality of Template A. The root cause of this issue lay in the attempt to automate this sheet as much as possible. However, this attempt at automation led to the referencing problem.

6.2. Revised solution

Template B, the result of the revisions, was designed for seamless institutionalisation, and contained five individual sheets: *weekly standard time recovery calc.*, *weekly standard time information*, *Line 1*, *Line 4* and *factory OEE*. The second sheet was an addition to the original Template A. This revised template was discussed, using benchmark data to maintain confidentiality. Template B was then an efficient, user-friendly, and accurate tool that aimed to add value at Company X.

6.2.1. Weekly standard time recovery calc. sheet revision

After revision, this sheet operated and performed the same function as Template A; however, the layout of the sheet was tailored to facilitate easier use and to ensure chronological flow. This targeted the second identified problem.

6.2.2. Weekly standard time information sheet addition

This sheet was a new addition to the proposed solution, and users were required to input data manually from the *weekly standard time recovery calc.* sheet into this sheet. Specifically, the total production mass (kg) per shift and the total standard time recovered (hr) per shift had to be input into the designated blue cells, which were clearly marked for user input. This needed to be done for each line per week *n*. These input cells were then referenced in the *Line 1* and *Line 4* sheets for further calculations. This sheet addressed the first and most detrimental problem that was identified. This solution effectively resolved this critical problem by ensuring that calculations in the subsequent sheets for each week *n* referenced the appropriate data from this sheet for each week, as required.

6.2.3. Line 1 and Line 4 sheet revision

The calculations performed in these sheets mirrored those in Template A. However, these calculations now referenced the input data in the *weekly standard time information* sheet instead of the previously referenced data in the *weekly standard time recovery calc.* sheet, which had led to the identified referencing problem. These sheets were also revamped to enhance their user-friendliness, addressing the fourth identified problem. To achieve this, the colour of some cells was removed to reduce the visual clutter. In addition, the constant planned running time was clearly stated at the top of these sheets, making future alterations and maintenance easier for Company X when capacity changes occurred. Both sheets followed the same structure, specific to the values associated with the respective lines.

6.2.4. Factory OEE sheet revision

The revised *factory OEE* sheet addressed the fourth identified problem, related to the ease-of-use. In this sheet, the colour scheme was adjusted to maintain consistency across the various sheets in Template B, resulting in a cleaner and more professional appearance. The line graph in Figure 4 was added to the *factory OEE* sheet in Template B to eliminate the third identified problem. This graph updated as week *n* values were input into the preceding sheets, enabling the calculation of Line 1, Line 4, and the overall factory OEE. It allowed management to monitor the OEE of Line 1, Line 4, and the entire factory, making it easier to identify promptly any unusual metric and its root causes. This, in turn, facilitated the swift formulation of strategies for rectification before any negative effects were carried over into the following week.

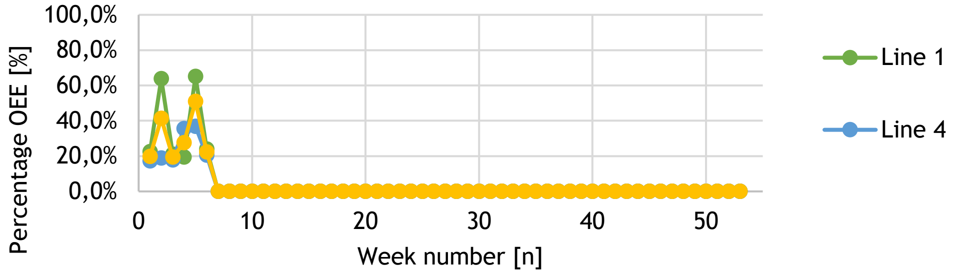

Figure 4: Line and factory OEE line graph - Template B

6.2.5. Overview of Template B activities

Figure 5 provides an overview of the activities performed per week n by the user and by the Excel workbook in Template B, resulting in the desired OEE metrics. The activities with prefix one, represent those executed in the weekly standard time recovery calc. sheet; the prefix two activities are newly added activities in the weekly standard time information sheet; the prefix three activities pertain to the Line 1 and Line 4 sheets; and the prefix four activities indicate the tasks in the factory OEE sheet.

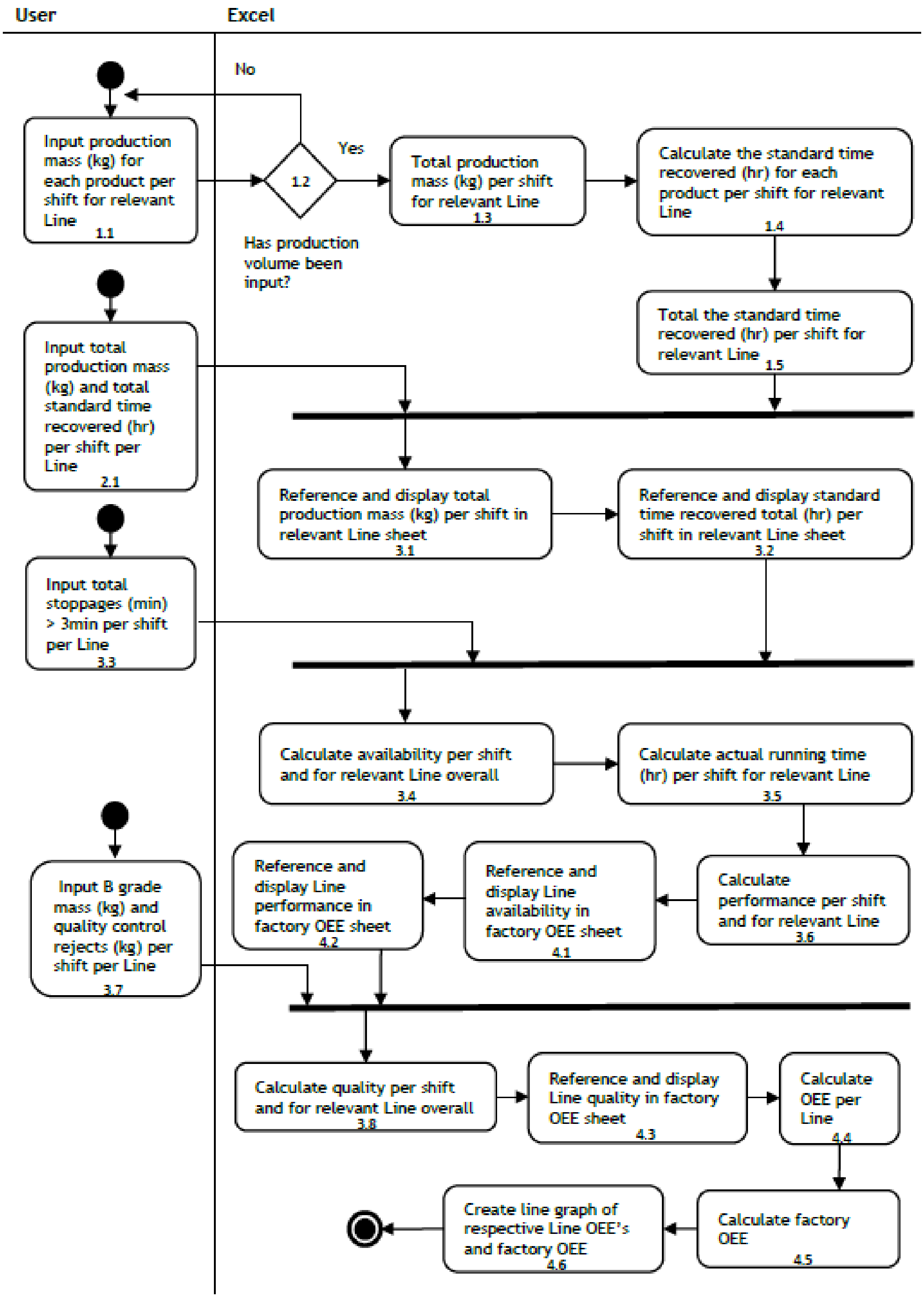

Figure 5: Activity diagram for Template B

7. CONCLUSION

This study reaffirms the relevance of traditional performance measurement systems (PMSs) in modern organisations in the context of the Fourth Industrial Revolution (4IR). For the maximal use of these systems, research needs to be constantly dedicated to exploring ways to adapt the existing systems to major technological advancements and to different industry demands. This means that the effectiveness of PMSs is highly contingent on their adaptation to the specific needs and advancements of the host organisation. Various factors influencing the successful implementation and use of PMSs in engineering organisations have been identified, bridging a gap between the literature and its applicability in modern organisations. These factors serve as a valuable diagnostic tool, enabling management to pinpoint reasons for the failure or ineffectiveness of their existing PMSs. By understanding and addressing these factors, organisations could enhance their operational efficiency and effectiveness. The study used the overall equipment effectiveness (OEE) metric as a customised solution to address the data barriers that impede the successful implementation and use of PMSs. This approach could serve as a roadmap for other engineering organisations like Company X to follow and would aim to reduce waste and increase productivity and cost savings. Future research should explore the factors affecting PMS success in 4IR-integrated engineering organisations in order to validate and expand these findings.

REFERENCES

[1] A. B. Badiru, The story of industrial engineering: The rise from shop-floor management to modern digital engineering. Boca Raton: CRC Press, 2018.

[2] A. Tung, K. Baird and H. Schoch, "Factors influencing the effectiveness of performance measurement systems," *International Journal of Operations & Production Management*, vol. 31, no. 11, pp. 1287-1310, 2011.

[3] A. Neely, M. Gregory and K. Platts, "Performance measurement system design: A literature review and research agenda," *International Journal of Operations & Production Management*, vol. 15, no. 4, pp. 80-116, 1995.

[4] L. F. Moura, E. P. de Lima, F. Deschamps, D. Etzion and S. E. da Costa, "Designing and implementing performance measurement systems based on enterprise engineering guidelines," *International Journal of Productivity and Performance Management*, vol. 72, no. 5, pp. 1239-1265, 2021.

[5] M. Busi and U. S. Bititci, "Collaborative performance management: Present gaps and future research," *International Journal of Productivity and Performance Management*, vol. 55, no. 1, pp. 7-25, 2006.

[6] R. A. Martins and E. Prancic, "Factors which affect the development of performance measurement systems," *Proceedings of the 2011 Industrial Engineering Research Conference*, 2011. [Online]. Available: https://www.researchgate.net/profile/Roberto-Martins-10/publication/290960013_Factors_which_affect_the_development_of_performance_measurement_systems/links/58bdfce545851591c5e9bbe6/Factors-which-affect-the-development-of-performance-measurement-systems.pdf

[7] F. Cunha, J. Dinis-Carvalho and R. M. Sousa, "Performance measurement systems in continuous improvement environments: Obstacles to their effectiveness," *Sustainability*, vol. 15, no. 1, 867, 2023.

[8] K. Khan and A. Shah, "Understanding performance measurement through the literature," *African Journal of Business Management*, vol. 5, no. 35, pp. 13410-13418, 2011.

[9] L. Kloviene and I. Uosyte, "Development of performance measurement system in the context of Industry 4.0: A case study," *Engineering Economics*, vol. 30, no. 4, pp. 472-482, 2019.

[10] A. Sardi, E. Sorano, G. Giovando and V. Tradori, "Performance measurement and management system 4.0: An action research study in investee NPOs by local government," *International Journal of Productivity and Performance Management*, vol. 72, no. 4, pp. 849-872, 2023.

K. Phusavat, P. Anussornnitisarn, P. Helo and R. Dwight, "Performance measurement: Roles and challenges," *Industrial Management & Data Systems*, vol. 109, no. 5, pp. 646-664, 2009.

[11] A. R. Rezaei, T. Celik and Y. Baalousha, "Performance measurement in quality management system," *Scientia Iranica*, vol. 18, no. 3, pp. 742-752, 2011.

[12] L. M. Rocha, E. Pinheiro de Lima, S. E. Gouvêa da Costa, Â. M. O. Sant'Anna and J. J. Angelis, "The roles related to performance measurement system use: A study based on clusters statistics analysis," *Gestão & Produção*, vol. 27, no. 4, e2708, 2020.

[13] Engineering Council of South Africa, *Ensuring the expertise to grow South Africa: Discipline-specific training guide for registration as professional engineering technologist in electrical engineering*, R-05-ELE-PT, Revision No. 4: 15 July 2021, Engineering Council of South Africa, 2021.

[14] M. Zubair, S. Maqsood, T. Habib, Q. M. U. Jan, U. Nadir, M. Waseem and Q. M. Yaseen, "Manufacturing productivity analysis by applying overall equipment effectiveness metric in a pharmaceutical industry," *Cogent Engineering*, vol. 8, no. 1, 1953681, 2021.
[15] S. Nakajima, *Introduction to TPM: Total productive maintenance*. New York: Productivity Press, 1988.
[16] Vorne Industries, "What is OEE?" 2023. [Online]. Available: https://www.oee.com/#:~:text=OEE (Overall Equipment Effectiveness) is, possible%2C with 20no Stop Time
[17] P. Clarke, "OEE and why it's important," 2023. [Online]. Available: https://slcontrols.com/en/oee-and-why-its-important/
[18] Y.-H. Hung, L. Y. O. Li and T. C. E. Cheng, "Uncovering hidden capacity in overall equipment effectiveness management," *International Journal of Production Economics*, vol. 248, 108494, 2022.
[19] E. M. van Aken, G. Letens, G. D. Coleman, J. Farris and D. van Goubergen, "Assessing maturity and effectiveness of enterprise performance measurement systems," *International Journal of Productivity and Performance Management*, vol. 54, no. 5, pp. 400-418, 2005.
[20] I. C. Fantozzi, S. di Luozzo and M. M. Schiraldi, "Industrial performance measurement systems coherence: A comparative analysis of current methodologies, validation and introduction to key activity indicators," *Applied Sciences*, vol. 13, no. 1, 235, 2022.
[21] H. R. Keathley, "Empirical investigation of factors that affect the successful implementation of performance measurement systems," PhD thesis, Virginia Polytechnic Institute and State University, Blacksburg VA, 2016.
[22] C. Suárez-Gargallo and P. Zaragoza-Sáez, "A comprehensive bibliometric study of the balanced scorecard," *Evaluation and Program Planning*, vol. 97, 102256, 2023.