MAINTENANCE APPROACHES FOR DIFFERENT PRODUCTION METHODS

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ABSTRACT

Various production methods are used in industry to manufacture or produce a variety of products needed by industry and consumers. The nature of a product determines which production method is most suitable or cost-effective. A continuous process is typically used to produce large volumes of liquids or gases. Batch processing is often used for small volumes, such as pharmaceutical products. This paper discusses a research project to determine the relationship between maintenance approaches and production methods. A survey was done to determine to what extent three maintenance approaches – reliability-centred maintenance (RCM), total productive maintenance (TPM), and business-centred maintenance (BCM) – are used for three different processing methods (continuous process, batch process, and a production line method).

OPSOMMING

Verskeie produksiemetodes word deur die industrie gebruik om 'n wye verskeidenheid produkte te vervaardig wat deur die industrie en verbruikers benodig word. Die aard van 'n produk bepaal watter produksiemetode die meeste koste-effektief is. Kontinue prosesse word gewoonlik gebruik vir die vervaardiging van groot volumes gasse of vloeistowwe. Enkelladingsprosesse word dikwels gebruik om klein hoeveelhede van 'n produk te vervaardig, bv. farmaseutiese produkte. Hierdie artikel bespreek 'n projek wat uitgevoer is om die verwantskap tussen instandhoudingsbenaderings en produksiemetodes te bepaal. 'n Meningsopname is gedoen om te bepaal tot watter mate drie benaderings – betroubaarheidgebaseerde instandhouding (RCM), totale produktiewe instandhouding (TPM) en besigheidgebaseerde instandhouding (BCM) – gebruik kan word vir drie alternatiewe produksiemetodes, naamlik kontinue prosesse, enkelladings prosesse, en die produksielyn metode.

1. INTRODUCTION

1.1 Background

Organisations are becoming increasingly dependent on technologies for productivity. These technologies are often embodied in physical assets that need to be maintained for the organisation to remain productive. Maintenance of such physical assets is normally based on proven maintenance approaches, philosophies, theories, and strategies. Deciding on a suitable approach or strategy is no trivial task. Industries are faced with a number of available maintenance theories, models, and frameworks. Most of these maintenance approaches or strategies are built on similar basic maintenance tactics, making it difficult to understand the differences between them. Vosloo and Visser [1] also highlighted the lack of standardised terminology in maintenance, making it difficult to do a scientific comparison between these different approaches. In this paper, the term 'maintenance approach' is used when reference is made to RCM, BCM, TPM, or other approaches.

Organisations dependent on physical assets for their productivity use different methods of production. Maintenance managers need to select a maintenance approach that is suitable for their operation and production method. It is therefore desirable to have a guideline to select or derive a suitable maintenance philosophy, approach, or strategy for an organisation based on its business needs, operational needs, and production methods.

1.2 Production methods

The selection of a production method is dependent on the business as well as the technical requirements of the organisation. Business requirements that influence such a decision include the volume of products to be produced, the degree of product customisation, and product lead time [2]. The relationship between product variety, volumes, process repeatability, and production methods is illustrated in Figure 1 below.

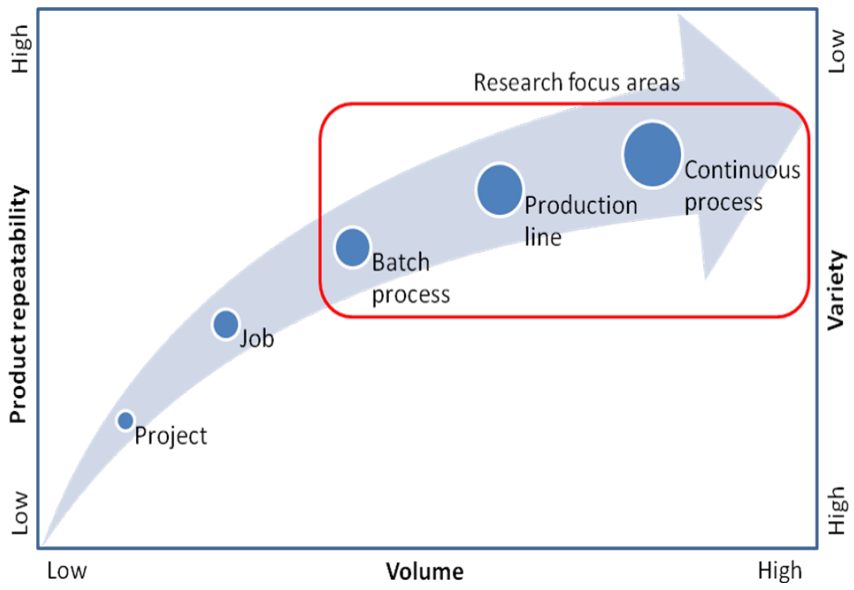

Figure 1: Relationship between variety, repeatability, and production method

The focus of this study and paper is on the top three methods; the batch process, production line, and continuous process. A brief overview of each method is discussed in the paragraphs that follow.

1.2.1 Batch process

The batch process method is used to produce goods or services where different products are produced in batches of product families. The process is set up initially to produce the first product family batch. Once the first batch of product is completed, the process is then set up for the second batch of the second product family. Products and services in a batch process are repetitive, and production volumes range from low to high. As a result, the batch production method is subdivided into low volume and high volume batch processes. Examples of low volume batches include printing, clothing manufacturing, and a doctor's room. High volume batches include canning of soft-drinks, and machining of small mechanical components such as bushes and washers.

1.2.2 Production line

The production line method is suitable for the production of one family of product in a large volume. The process is often directed by a conveyor belt or an assembly line. In a production line, the production process is set up once before production begins, and will only be changed once a product family is discontinued. This is different from a batch process, where the set-up is changed between batches of different product families. Employees on a production line are allocated to different stages of production along the production line, and they often specialise on assembling specific components. An example of a production line is the assembly of motor vehicles.

1.2.3 Continuous process

The continuous process method comprises a number of sequential stages of converting raw materials into one or more products. Such a process is often highly automated and physical asset intensive. Continuous processes are often designed to operate 24/7, and any breakdown in production process equipment results in downtime and a high production loss. Examples of a continuous process include oil refineries and power stations.

1.3 Maintenance approaches

A number of different maintenance approaches, sometimes referred to as strategies or philosophies, are currently available for application in all production methods. The fundamental characteristics of these maintenance approaches are fairly similar, but their focuses are different. Reliability-centred maintenance (RCM) originated in the aviation industry, and is focused on equipment reliability [3]. Total productive maintenance (TPM) originated in the assembly line industry, and is focused on improving the quality of people and processes [4]. Business-centred maintenance originated in the process industry, and focuses on performing cost-effective maintenance to achieve business goals [5].

Maintenance of physical assets has been needed ever since people started building them. The need for maintenance management was triggered by an increase in the number, size, and complexity of assets, and the increased specialisation of maintenance tasks to be performed.

All maintenance approaches or strategies use a number of basic types or tactics for each asset of the total system. Campbell and Reyes-Picknell [6] discuss the main tactics that can be applied to the maintenance of the components of a technical system. The four tactics that are most often used are highlighted below.

- **Operate to failure (OTF)** – equipment is run until a failure occurs, when a replacement is usually performed. This tactic is often the cheapest, since the full design life of the component is utilised. But it is not good practice when the consequence of failure is severe, such as loss of life or a major release of harmful substances.
- **Time-based maintenance (TBM**) – replacement or cleaning is performed at predetermined time or usage intervals. This tactic is often used for simple components that exhibit a definite wear-out failure mode with a narrow failure distribution. A drawback is that only part of the useful life of components is actually utilised.

- **Condition-based maintenance (CBM)** – some parameter that indicates the condition of the equipment is measured continuously or periodically, and replacement is performed when the condition is no longer acceptable.
- **Fault-finding maintenance (FFM)** – periodic checks are performed to determine whether the back-up equipment, redundant equipment, or protective equipment is still fully functional. If not, repair or replacement is performed [7].

1.4 Research problem

A large processing plant with a number of business units that produce different products such as coal, gases, liquid fuels, and specialist chemicals was selected as a case study to investigate maintenance approaches. In addition to the business units, there are also different workshops: diesel workshops, a central workshop, and machining workshops. The operations at this complex are therefore highly versatile in both product range and production methods.

The business units implemented different business approaches and technologies in a quest to become world class in their operations. This resulted in a fragmented approach, and management therefore initiated a strategy to encourage business units to work together to achieve excellence for the overall operation. Maintenance approaches within these different business units need to be standardised in compliance with the company's overall way of performing maintenance management.

At present, the larger business units implement the RCM approach in their operations. These business units have more influence on the entire organisation due to their significant contribution to the bottom line. Decisions on maintenance approaches, technologies, and tactics can easily be made by larger business units, and cascaded down to smaller business units and supporting workshops for implementation. The question can then be posed: Should the same maintenance approach be used for all business units, irrespective of the production method used?

1.5 Research objectives

The objective of this research study was to investigate the relationship between different maintenance approaches and different production methods. Such a relationship can assist in the development of a pre-production maintenance approach decision (PPMAD) model for the company as a whole. Such a model could provide a framework that would enable maintenance managers to decide on a suitable maintenance approach during the design phase of the physical assets. This could allow the development of maintenance life plans, maintenance tactics, and maintenance schedules to begin prior to plant commissioning.

2. LITERATURE

2.1 Background

The economy of scale requires a large capital investment to design, develop, and construct a processing or manufacturing facility. The two new coal-fired power stations currently under construction in South Africa are examples of huge investments in electricity production. Investors allocate their money with the aim of gaining some return on their investments. It is therefore important for physical assets to be highly reliable and available for the entire duration of the expected or design life of the overall asset.

2.2 Maintenance

Dhillon [8] defines maintenance as "a collection of actions executed on an asset with the aim of retaining an asset in, or restoring it to, a specified condition". The maintenance function is an essential part of any asset intensive organisation, and needs to support the organisation's business objectives. Maintenance managers need to understand that the maintenance function cannot operate on its own. For maintenance to contribute positively to the bottom line of the business enterprise, maintenance personnel need to realise that they are part of an overall production strategy [9].

Maintenance is essential to ensuring that physical assets are reliable and available to deliver products or services. In large facilities the maintenance workforce could comprise up to 70 per cent of the total workforce in the company [10]. When considering the financial impact of maintenance, both direct costs (labour, material, spares, tools, information, and contractors) and indirect costs (lost revenue due to downtime, lost reputation, customer compensation, and penalties) should be included [6].
Various classifications for maintenance are provided in the literature. Figure 2 shows the classification of the British Standard, BS EN 13306 [11].

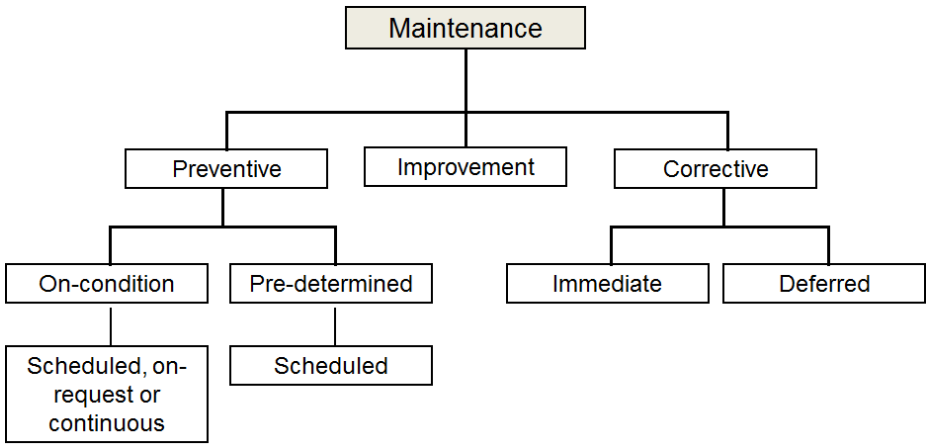

Figure 2: Major maintenance types or tactics (Adapted from BS 13306 [11])

Various maintenance approaches such as RCM and BCM employ most or all of the maintenance types or tactics in Figure 2. All maintenance approaches encourage the use of preventive tactics, although corrective maintenance tactics are also used. All facilities have some mix of the preventive and corrective tactics, and theoretically there should be a preventive/total maintenance ratio that minimises the total maintenance cost. However, this optimum ratio is not easily determined.

2.3 Reliability-centred maintenance

The need for more reliable aircraft increased greatly during and just after World War II. Large airplane manufacturers also realised the need for reliable passenger airplanes, and the development of new generation planes accelerated. The development of the reliability-centred maintenance (RCM) approach in the early 1960s was a direct response to the need for more reliable airplanes. The main goal of the RCM approach is to maximise the reliability of the physical asset by identifying the failure modes of the items and components of a system, and ranking the consequence of each failure mode. Preventive action is then performed if the consequences of failure are safety related or hidden to the operators. The output of the RCM process is a life plan for each component of a system. This life plan consists of a list of preventive tasks (scheduled discard tasks, scheduled restoration tasks, or on condition tasks) for a total system. Scheduled failure-finding tasks are also identified for components that have hidden failure consequences. A detailed discussion of RCM is provided by Moubray [3] and Ben-Daya et al. [12].

2.4 Total productive maintenance

Quality systems were introduced in Japanese manufacturing industries in the 1960s and 70s. The application of total quality management (TQM) in the maintenance departments eventually lead to the development of an approach tailored to the maintenance environment. The name ‘total productive maintenance’ (TPM) was adopted for this approach. The focus of TPM is to develop quality maintenance workers and adopt a zero defect, zero loss, and zero failure approach towards maintenance management. TPM is often viewed as a people-centred approach to maintenance, and is therefore an approach or philosophy for all workers in the business enterprise. A main feature of TPM is to

eliminate all machine losses to maximise overall equipment effectiveness (OEE). Another main feature is the use of small work groups to investigate and solve recurring problems and failures in the plant. Suzuki [4] provides a comprehensive treatise on the development of TPM for the process industry. Wireman [13], Mobley [14], and Willmott [15] also discuss the fundamental principles of TPM.

2.5 Business-centred maintenance

Kelly [5] developed a maintenance approach in the 1980s that he termed 'business-centred maintenance' or BCM. This approach was developed in response to the need for a more cost-effective model for maintenance, but with a high priority for safety. BCM is a generic approach that can be applied in most industries or to most manufacturing/production systems or service systems, such as chemical process plants, power stations, fleet type systems (buses, trains), or communication networks. BCM emphasises the importance of aligning the maintenance function with corporate objectives. A thorough understanding of the operation of the system is then used as input for the top-down bottom-up analysis, in which a life plan is developed for the components, items, and units of the system. The life plan for a unit defines which maintenance procedures (condition based maintenance, fixed time maintenance, or operate to failure) are effective, and a maintenance schedule can thus be formulated for each unit.

2.6 Comparison of maintenance approaches

An overview and comparison of RCM, BCM, and TPM, indicating the advantages and the disadvantages, is shown in Table 1 below.

Table 1: Advantages and disadvantages of maintenance approaches [11]

RCM	BCM	TPM
ADVANTAGES		
• Traceability • Cost saving • Rationalisation • Operator & maintenance involvement • Plant reliability improvement	• Accuracy • Business-centred • Integrated auditing possibility	• Productivity improvement • Quality improvement • Cost reduction • Operator involvement
DISADVANTAGES		
• Complexity • Extensive need for data • Reliability-centred • Does not focus on economic problem	• Complexity • Extensive need for data	• Not a true maintenance concept • Lacks decision rules on maintenance policies • Does not focus on economic problem

2.7 Suitability of maintenance approaches

Only a few references report on research studies that evaluate the suitability of different maintenance approaches for different industries or types of assets. Kennedy [16] discusses the properties of RCM and TPM and compares the two approaches for compatibility. Campbell and Jardine [17] developed a checklist to guide maintenance practitioners when they evaluate whether RCM is suitable for their operations. This checklist is limited to RCM, and cannot be used to evaluate whether other maintenance approaches are suitable. Kelly [5] also discusses the suitability, advantages, and disadvantages of RCM, TPM, and BCM (the last of which he developed).

From the limited literature, it is found that RCM is focused on asset reliability, and is most suited for high risk systems. TPM is focused on people factors and organisational culture, and is most suited for assembly type industries, although it has also been applied in the

continuous process industry. BCM is focused on aligning the maintenance function with organisational or business objectives.

3. RESEARCH METHODOLOGY

3.1 Background

Ten business units of a company that performs chemical processing and mining were targeted to collect data on the maintenance approaches and processing methods applied at the plants and facilities. Four of these business units were involved in continuous processes, three were involved in batch processing, and the remaining three were involved in production line processes.

A structured questionnaire was prepared and sent to potential respondents within the ten business units or delivered personally to individuals. The hierarchical levels involved in this study were engineering managers, engineers, maintenance managers, technicians, chief foremen (maintenance), foremen (maintenance), and artisans. The respondents were selected based on their basic understanding of maintenance and maintenance concepts.

3.2 Data collection

A questionnaire was developed to evaluate the perceptions and beliefs of respondents within the company. The first question asked the respondent to identify the business in which he/she was involved. The second question requested the designation (hierarchical level) of the respondent, and the third question asked whether he/she was involved in continuous process, batch process, or production line methods. The remaining 11 questions asked for information related to the maintenance approaches – RCM, TPM, and BCM. The complete questionnaire is available from the author [18]. The questionnaire was delivered by hand to middle management, and employees filled in the form immediately. The questionnaire was sent to senior management by e-mail and returned by e-mail.

3.3 Business units

Thirty-seven respondents from different business units of the company participated in this study. Figure 3 below depicts the representation of the respondents per business unit. Business units C1 to C3, as well as 'Other', are associated with the continuous process production method. Units B1 to B3 are associated with the batch process method. Units P1 to P3 are associated with the production line method.

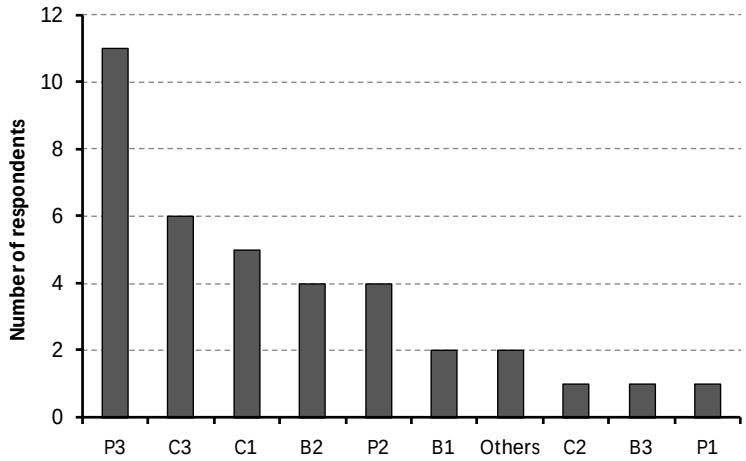

Figure 3: Respondents per business unit

As shown in Figure 6 below, the number of respondents from the different units was too small to compare the results against each other, and the data for the units was therefore grouped together for the three production methods only.

3.4 Production methods

Three production methods were investigated in this study: batch, production line, and continuous. Table 2 indicates the number of respondents who were involved in each of these three production methods.

Table 2: Number of respondents per production method

Production method	Number of respondents	% of total
Batch processing	7	18,9
Production line	16	43,2
Continuous processing	14	37,8

As Table 2 indicates, the largest number of respondents was involved in production line facilities, and the smallest number in batch processing.

4. RESULTS

4.1 Awareness of maintenance approaches

The first set of questions in the questionnaire determined the level of awareness of different maintenance approaches held by the respondents. The awareness level was first measured by determining the number of respondents who have in the past attended any formal training or course on each of the three maintenance approaches. The second method of measuring the level of awareness was through the number of respondents who have, in the past, participated in a team that implemented any of the maintenance approaches within a business unit.

4.1.1 Awareness and management level

The level of awareness as measured by the level of formal training is indicated in Figure 4 below.

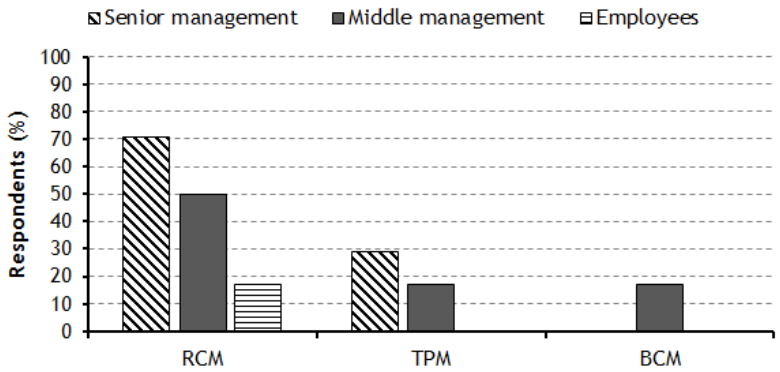

Figure 4: Awareness of maintenance approaches (formal training)

Figure 4 shows that the awareness level is highest at senior management level, and for the RCM maintenance approach. The awareness level for TPM is low; for BCM it is very low at all levels.

The level of awareness determined through experience in actual implementation is indicated in Figure 5 below.

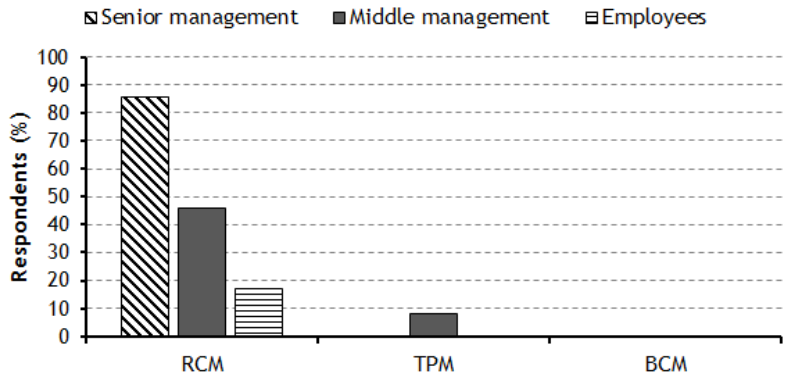

Figure 5: Awareness of maintenance approaches (implementation experience)

From Figure 5 it is clear that the highest awareness, based on implementation experience, is also highest at senior management level and for the RCM methodology. The level of awareness for TPM and BCM is even lower than awareness based on training, shown in Figure 4.

4.1.2 Awareness level and production method

The relationship between awareness level and the production method used was also determined, and the relationship with formal training is shown in Figure 6.

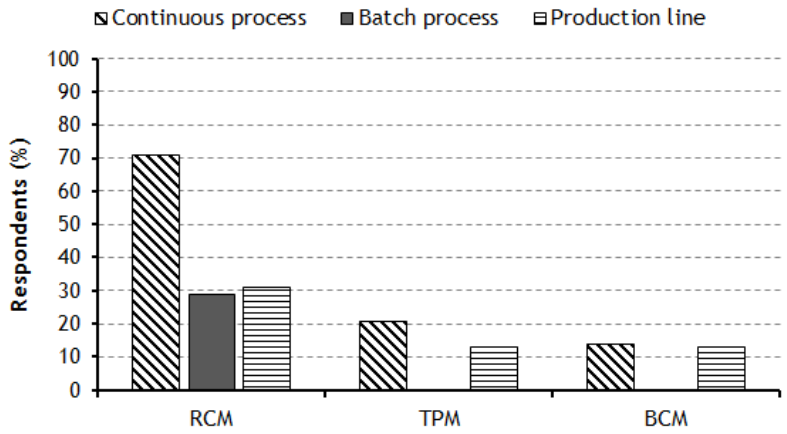

Figure 6: Awareness of maintenance approaches per production method (formal training)

Figure 6 shows that awareness is by far the highest for RCM and the continuous process production method. There is some awareness of TPM and BCM for the continuous process and the production line, but none for the batch process production method.
Awareness determined through actual implementation experience is indicated in Figure 7.

Figure 7 shows that the awareness level, based on implementation experience, is also highest for RCM and the continuous process production method. There is some awareness of TPM and BCM for the continuous process and the production line, but none for the batch process or production line method.

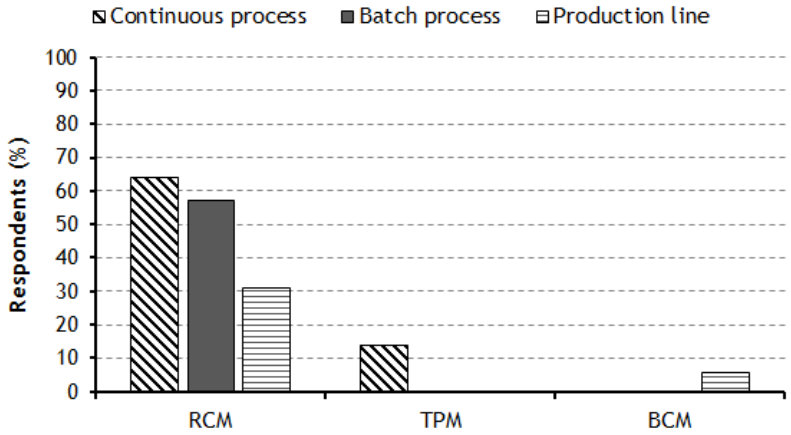

Figure 7: Awareness level of maintenance approach per production method (implementation experience)

4.2 Suitable maintenance approach

Key characteristics of each of the maintenance approaches were converted into a number of statements that described different requirements for physical assets. Respondents were asked to select only three statements from the list that best describe their maintenance requirements. Table 3 shows the classification of statements according to the maintenance approaches they represent. The maintenance approach was not given for these statements.

Table 3: Classification of research statements according to their maintenance approaches

Maintenance approach	Statement description
RCM	Assets need to be highly reliable Failure of the assets can easily lead to SHE hazards Financial implication of one hour in downtime is very high
TPM	Operators need to carry out first line maintenance tasks (e.g. lubrication) Maintenance teams and operators need to collaborate in their efforts for continuous improvement
BCM	Maintenance teams need to understand the company business objectives Number of maintenance tasks need to be optimum to avoid cost of over-maintaining

Table 3 shows that RCM has three statements, while TPM and BCM have only two statements each. To ensure a fair sample, the number of RCM statements selected by respondents was multiplied by a factor to give them equal weight with both TPM and BCM statements.

The number of statements selected by each respondent for each maintenance approach was accumulated. The results are shown in Figure 8 on the next page.

Figure 8 shows that business units associated with continuous processes were clearly more concerned with asset reliability – a feature of the RCM approach. Respondents from business units associated with batch processes had a preference for TPM – involving asset care by the operators. Respondents from business units that run production lines clearly favoured the RCM approach and its associated reliability and availability.

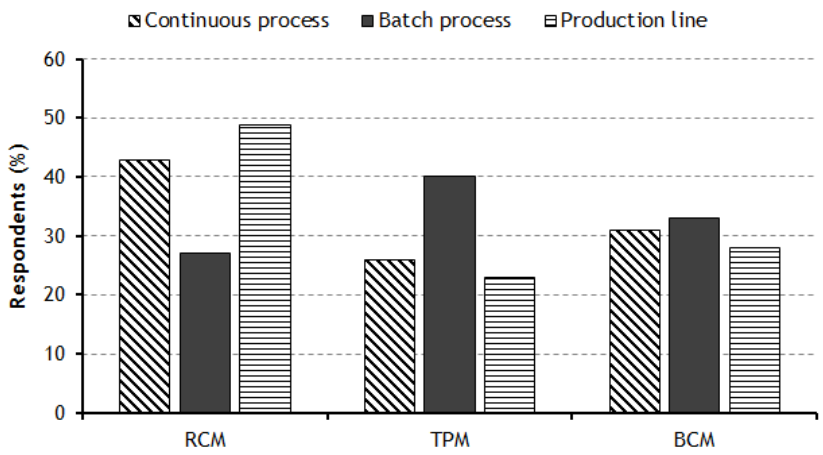

Figure 8: Relationship between maintenance approach and production method

4.3 Preferred maintenance approach

The respondents were also questioned directly on which of the three maintenance approaches they would prefer as a method for developing a maintenance plan for a group of physical assets. The results are shown in Figure 9.

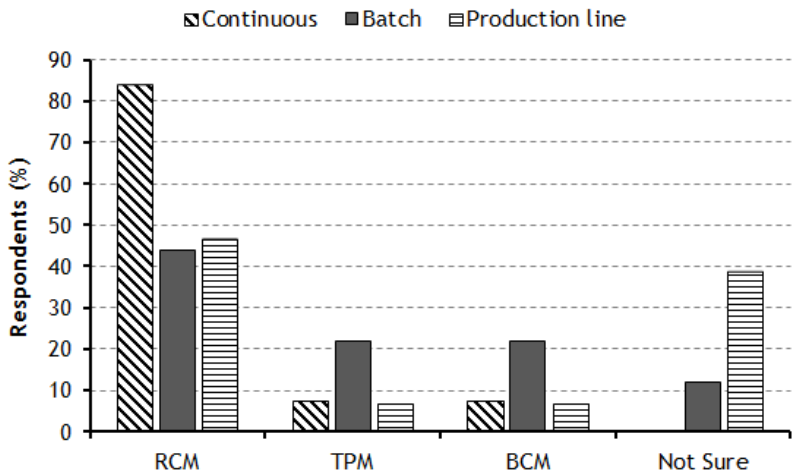

Figure 9: Preferred maintenance approach per production method

It is clear from Figure 9 that respondents associated with continuous processes by far prefer the RCM approach to developing a maintenance plan, and as the way maintenance should be performed in the business enterprise. Respondents associated with batch processes also preferred the RCM approach, although about 20 per cent indicated TPM and 20 per cent indicated BCM as the preferred approach. About half of the respondents associated with the production lines indicated RCM as the preferred approach, but a significant ratio (~ 40 per cent) were unsure. These employees probably had little exposure to any of these three approaches in the maintenance environment.

4.4 Appropriate time to decide on a maintenance approach

Respondents were asked to indicate when in the life cycle phase of an asset is most suitable to make a decision on the appropriate maintenance approach for that asset. The results are shown in Figure 10.

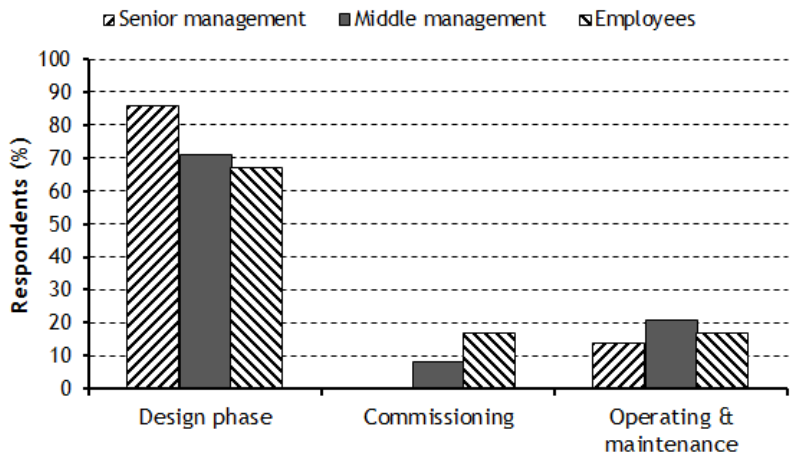

Figure 10: Life cycle phase to decide on a suitable maintenance approach

The majority of respondents from all three levels in the organisation agreed that the design phase of an asset is the most appropriate time to make the decision about the maintenance approach to be used.

4.5 Discussion of results

The main results of the survey can be summarised as follows:

- Awareness level is highest at senior management level and for the RCM maintenance approach.
- Awareness level is highest among those respondents involved in the 'continuous process' production method.
- Respondents involved in 'continuous processes' preferred an approach that provided asset integrity and reliability. This can be associated with the RCM approach.
- Respondents involved in 'batch processes' preferred an approach that involved the operators in the maintenance of the assets. This can be associated with the TPM approach.
- In answering a direct question about which maintenance approach is preferred, respondents from all production methods preferred the RCM approach.
- Respondents from all three levels agreed that the design phase of an asset is the most appropriate time to make the decision on the maintenance approach to be used.

5. CONCLUSIONS

The purpose of this study was to investigate suitable maintenance approaches for different production methods. The research was done as a case study at a complex processing plant with different business units that operate physical assets using different production methods. The business units have implemented different business approaches and technologies in a quest to become world class in their operations. This resulted in a fragmented approach, and management therefore initiated a strategy to encourage business units to work together to achieve performance for the overall operation. The same maintenance approach is not necessarily the best approach for business units that operate assets using different production methods.

This research study investigated the current trends for the different production methods: continuous process, batch process, and production line methods. The survey indicated that the awareness level is highest for the RCM approach and the continuous process production method. Workers involved in the continuous process method preferred an approach that would provide asset integrity and availability. Workers involved in the batch process

method preferred an approach that involved the operators in certain maintenance tasks and activities. Operator maintenance is a key feature of the TPM approach.

A positive outcome of this study was that the majority of respondents from all levels of management (an average of 72 per cent) involved in the survey were of the opinion that decisions about the maintenance approach, as well as about the specific maintenance tactics to be used for each component or item of the asset, should be made during the design phase of the asset life. The operation and maintenance phase of an asset is often neglected during the design phase, but the application of the systems engineering methodology during development requires decisions and consideration of the maintenance of the asset – decisions that affect reliability, availability, and maintainability (RAM).

6. RECOMMENDATIONS

The number of respondents for the continuous process production method was fairly good, but the number for the other two methods was insufficient to extrapolate the findings to other industries. It is therefore recommended that a similar survey be conducted in a number of different companies that collectively operate plants and facilities using different production methods, such as continuous process, batch process, and production line. It is also important that different managerial levels, including middle management and front-line workers, are involved.

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