Total Productive Maintenance (TPM) Implementation Framework for Cable Manufacturing Company

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Abstract: This paper seeks to show that the longer production continues with no interruptions, the higher the production will be. However and inevitably, as machines continue in use, wear and fatigue become more pronounced with increased frequency. As a result, maintenance is necessary to help restore the machine to a functional state, preferably for as long a time as possible. So at the end of the day, a strategy is necessary to assist the whole operation attain a high plant availability. In the process as well, the strategy is not expected to hinder or disturb any other policies that might be in place, such as the environmental policy. The particular research sought to determine the strengths and weaknesses of the current maintenance practices at a cable manufacturing company, and then recommend possible strategic solutions. The research sought to ascertain the level of commitment and involvement of the management in the implementation and sustaining of continuous improvement as well as involvement in strategic changes such as the implementation of Total Productive Maintenance (TPM) for all employees. The paper concludes by affirming the possibility of using the holistic TPM approach which is people centred.

Key words: production, maintenance, plant availability, cable manufacturing, TPM

I. INTRODUCTION

The principles of Total Productive Maintenance (TPM) have been around for some time and much hard work has been done on the subject by various organisations. TPM is about harnessing human and material resources in the most effective way to achieve an organisation’s objectives [1]. It is a management philosophy which recognises that customer satisfaction, plant and people’s health, safety, environmental considerations and business objectives are mutually dependent. Investment in material things is an accepted and well developed management practice but the application of TPM primarily involves investment in time, people and systems: time to implement new concepts, time for people to recognise the benefits, and time for people to move forward into new and different company cultures. The participation organisation has to take this vision on board if TPM is to succeed [1].

The objectives and goals of TPM can be many and are for the organisation to decide. These may include customer satisfaction, business objectives such as profit growth and market growth. The objectives should include responsibility towards society including the healthy and safety of people within the organisation, the customers receiving the product or service and the need to protect the environment.

In industrial set ups, the main focus is usually on maintenance; which is the management, control, execution and quality of those activities which will ensure that optimum levels of availability and overall performance of plant are achieved, in order to meet business objectives [2]. In 1988, the Department of Trade and Industry, UK, commissioned a report “Managing Maintenance into the 1990s”. One conclusion of this report was that a 5% improvement in machine availability could result in a 30% improvement in net profit [3].

A direct inference to this statement is that this is possible by eliminating the six losses which reduce the effective production time. The six losses have been divided into three groups shown in the table below:

<table>
<thead>
<tr>
<th>Table 1: The six losses [5]</th>
</tr>
</thead>
</table>
| **DOWNTIME** | • Failure from breakdown  
|               | • Set-up and adjusting  |
| **SPEED LOSSES** | • Idling and minor stops  
|                 | • Reduced speed  |
| **DEFECT/QUALITY** | • Process defect  |
II. WHAT IS MAINTENANCE?

Maintenance can be defined as “the combination of all technical and associated administration actions intended to retain an item in or restore it to a state in which it can perform its required function”. Maintenance is “all activities that are performed to maintain and restore an equipment in such a condition that the planned production can be accomplished free of troubles” [6]. It can also be said to be the “management, control and execution and quality of those activities which will ensure that optimum levels of availability and overall performance of plant are achieved in order to meet business objectives, which can be achieved through use of a number of resources such as people, spares and tools, so as to ensure availability and condition of plant.” [8]. From a technological point of view, the term “tero-technology” is used to encompass maintenance and defined as “the branch of technology and engineering concerned with the installation, maintenance and replacement of industrial plant and equipment with related subjects and practices” (from the Oxford English Dictionary). Furthermore, from an accounting point of view, maintenance can also be dubbed the “Asset Preservation”. Maintenance must include the entire project, research and development, manufacturing, utilisation, and scrapping [4].

The purpose of good maintenance is to minimise bad maintenance- and downtime cost – at a given quality of production – while at the same time fulfilling the requirements of safety, to eliminate or reduce failures; prevent wear, destruction or breakdown.

III. WHICH MAINTENANCE STRATEGY TO ADOPT?

From the information given above, some of the maintenance strategies presented appear to have advantages over others, but it does not follow that it is feasible to adopt these in all cases. Techniques or methods to help make the most appropriate decision have been developed. Some of these are explained below.

3.1 DECISION TREES

The consultants Wolfson Maintenance, have developed one of these [8]. The decision is primarily based on the failure pattern, but also the mean time between failures. Both of these are determined by historical data of the machine. The result is a list by preference of the maintenance strategy that should be adopted.

3.2 FAILURE MODE EFFECT ANALYSIS (FMEA)

For best results, this technique should be applied at the early engineering stage. To carry out an FMEA, a table is constructed which lists every probable failure mode and the resulting effect on the machinery, production system, people and safety. Typical data would include: part identifier, probable failure cause, failure effect, and how the failure can be reduced or eliminated, as shown in the next example [10].

<table>
<thead>
<tr>
<th>Part identifier</th>
<th>Failure</th>
<th>Cause of failure</th>
<th>Effect of failure</th>
<th>How to Eliminate Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear</td>
<td>Broken Tooth</td>
<td>Wear</td>
<td>Will not Transit Power</td>
<td>Heat Treat</td>
</tr>
</tbody>
</table>

Heat-treating becomes the solution to the problem.

3.3 MODES OF FAILURE

A plant machine or equipment will experience different modes of failure throughout its life. These are [7]:
- Run-in - these are failures in new equipment, possibly from manufacturing errors.
- Useful life – failures are generally random in nature.
- Wear-out- the equipment is nearing the end of its useful life. Failures increase as a result of components wearing out.

Not all components follow this pattern. There are some which follow a more random failure pattern (e.g. light bulbs).

3.4 COST SAVINGS

Data supplied by monitoring devices can help users avoid unplanned stoppages. The devices provide instant reports on a regular basis, and following the trends, scheduled maintenance windows can be utilised. This saves both time and money, and facilitates timely procurement of spares and optimum stock levels. The effectiveness of maintenance can affect profitability in three ways [3]:

1. Lost production through plant unavailability
2. Cost of maintenance resources
3. Life of the plant
This implies that the maintenance function (itself regarded a cost) can have a direct measurable effect on the company’s balance sheet (remember “asset preservation”).

3.5 IMPROVEMENT ON MAINTENANCE EFFICIENCY
One renders maintenance more effective by obtaining and implementing a preventive maintenance plan (for recurrent preventive maintenance work such as cleaning, lubrication, repairs, exchanges, condition monitoring and inspection.

IV. WHAT HAPPENS WHEN MAINTENANCE IS NOT EFFECTIVE?
This inevitably results in [5]:
- Excessive machine breakdowns.
- Frequent emergency maintenance work and shortened life span of facility.
- Disproportionate investment in spare parts and maintenance materials.
- Poor utilisation of maintenance staff.
- Loss in production output and lower quality products.
- Panic operation changes and excessive overtime costs (both maintenance and production).

V.MACHINE INEффICIENCIES VS. COMPANY PERFORMANCE
Below is a step by step causal analysis on shoddy maintenance and its effect on company performance.

1. Causes
- Minimal maintenance effort.
- Incomplete maintenance history.
- No inspection.
- Limited inspection.

2. Primary
- Equipment poorly maintained.
- Increased need for spares.
- Frequent equipment breakdowns.
- Low equipment utilisation and interruption to product.
- Poor quality parts produced, increased scrapped and reworked parts.

3. Operational effects
- Decreased morale.
- Overtime and low productivity.
- Increased order to delivery lead-time, and poor due date performance.

4. Business effects
- Customer dissatisfaction.
- Low sales leading to poor profit.
- Increased cost [1].

VI.THE RELATIONSHIP BETWEEN THE CONCEPTS OF RELIABILITY
Reliability affects the plant running directly and therefore it is necessary to have a form of reliability measure. This can be done by applying the following measures [4]:
- Functional reliability measure, which is the mean time to failure (MTTF).
- Maintainability measure, which is the mean time to repair (MTTR).
- Supporting measure, which is the mean waiting time.

VII.LIMITATIONS IN DATA COLLECTION
For data collection in the company, the limitations in the main had to do with:
- Unreliable records in some cases.
- False information from some employees.
- Production dependency on customer’s demand.
- Production is disturbed by foreign currency shortages.
- Time to make investigations, implement and observe changes are limited.
- Late payments by some of the main customers.

All assessments and recommendations were based on the results obtained from the investigations made.

The Cable Manufacturing Company was established in Zimbabwe in 1947, and manufactures a wide range of low voltage power cables, general wiring cables and telecommunication cables. The company has been until recently part of a worldwide cable manufacturing Group and thus, can draw from first world cable manufacturing and development expertise.

It was the first company in Zimbabwe to be awarded SAZ ISO 9002 certification in 1994. The customer is therefore assured of world-class quality cable all the time. In addition, a comprehensive product and technical advisory is available from experienced staff.
Subsequently it was the first company in Southern Africa to be awarded SAZ ISO 14001 certification in 1999.

VIII. PRODUCTION CAPACITY

With minimum disturbance, the factory produces an average of 100 tonnes per week of products, an equivalent of 400 tonnes for a four -week month, and 500 tonnes for a five week month. This tonnage increases or decreases depending on the nature of the product. For large diameter power cables, the tonnage can be higher than the 100 tonnes per week, whereas it can be smaller for small cables. On the other hand, large cables take longer on the production line. However, profit per kilogram of product is higher for smaller cables than it is for large ones. This then becomes a bottleneck in the production procedure, and needs proper planning and 100% machine availability. Scrap rates have to be reduced, thus maintaining and improving quality, at the same time improving on maintenance management.

If smaller cables are to be run, most of the machines will be working. Thus breakdowns are likely to be higher, resulting in higher downtime, and the need to have a well planned maintenance system. Dirt in form of dust from chalk, scrap in terms of PVC and faulty cables is inevitable, but through continuous improvement the company aims at keeping this at the minimum levels possible.

XI. MACHINES

The following is a list of machines currently in use. In the table, functions of the machines are also highlighted. Of importance to note also are the machines that can easily cause bottlenecks due to multiple use when compared with other machines.

Table 4: Machine list

<table>
<thead>
<tr>
<th>Machine No.</th>
<th>Machine Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drum Twister Lay-up</td>
<td>Laying up wires</td>
</tr>
<tr>
<td>2</td>
<td>Drum Twister Armourer</td>
<td>Armouring cables with steel wire or stranding</td>
</tr>
<tr>
<td>3</td>
<td>Outokumpu (OTK)</td>
<td>Copper melting and rod casting</td>
</tr>
<tr>
<td>4</td>
<td>GG Rewinder</td>
<td>Stranding and laying up</td>
</tr>
<tr>
<td>5</td>
<td>NM100</td>
<td>Insulating and sheathing</td>
</tr>
<tr>
<td>6</td>
<td>42 Armour No. 1</td>
<td>Armouiring cables</td>
</tr>
<tr>
<td>7</td>
<td>42 Armour No. 2</td>
<td>Armouiring cables</td>
</tr>
<tr>
<td>8</td>
<td>Heinrich Rod breaker</td>
<td>Wire drawing</td>
</tr>
<tr>
<td>9</td>
<td>Heinrich intermediate</td>
<td>Wire Drawing</td>
</tr>
<tr>
<td>10</td>
<td>Heinrich 8-wire</td>
<td>Wire drawing</td>
</tr>
<tr>
<td>11</td>
<td>Heinrich Buncher</td>
<td>Bunching</td>
</tr>
<tr>
<td>12</td>
<td>DS130</td>
<td>Insulating and sheathing</td>
</tr>
<tr>
<td>13</td>
<td>BM80-1</td>
<td>Insulating</td>
</tr>
<tr>
<td>14</td>
<td>BM80-2</td>
<td>Insulating</td>
</tr>
<tr>
<td>15</td>
<td>37 Strander</td>
<td>Stranding (up to 37 strands)</td>
</tr>
<tr>
<td>16</td>
<td>24 Strander</td>
<td>Stranding (up to 24 strands), mainly aluminium cables.</td>
</tr>
<tr>
<td>17</td>
<td>18 Strander</td>
<td>Stranding (up to 18 strands)</td>
</tr>
<tr>
<td>18</td>
<td>Unity Strander</td>
<td>Stranding</td>
</tr>
<tr>
<td>19</td>
<td>Northampton</td>
<td>Laying up</td>
</tr>
<tr>
<td>20</td>
<td>Francishaw</td>
<td>Insulating</td>
</tr>
<tr>
<td>21</td>
<td>PG 1000</td>
<td>Laying up</td>
</tr>
<tr>
<td>22</td>
<td>Goddridge</td>
<td>Laying up</td>
</tr>
<tr>
<td>23</td>
<td>Sheathing line</td>
<td>Sheathing</td>
</tr>
<tr>
<td>24</td>
<td>Twinners 1&amp;2</td>
<td>Twinning</td>
</tr>
<tr>
<td>25</td>
<td>Braiders</td>
<td>Braiding (for optical fibres and communication cables)</td>
</tr>
<tr>
<td>26</td>
<td>PS coiler</td>
<td>Coiling of wire or armouring machines</td>
</tr>
<tr>
<td>27</td>
<td>Compressor</td>
<td>Compressing air</td>
</tr>
</tbody>
</table>

X. PRODUCT RANGE

10.1 METALLIC TELECOMMUNICATION CABLES

Cables are manufactured to British Telecom and Zimbabwe’s Posts and Telecommunications (PTC) specifications. However, the company can produce a wide range of telecommunication cables for worldwide applications to national and international standards or customised to meet operator’s specific requirements. These cables are in two broad categories – internal and external telecommunication cables.
10.2 POWER CABLES

The range of power cables is rated at 600/1000V and 1900/3300V and supplies both armoured and unarmoured cables which conform to British Standards (BS), South African Bureau of Standards (SABS), Standards Association of Zimbabwe (SAZ) and to international requirements as defined in IEC standard 502.

Cables can also be supplied to the national standards of other countries; these range from PVC, XLPE, LHC and LSF cables in all sizes up to 300mm squared.

10.3 GENERAL WIRING CABLES

The company also manufactures a wide range of wiring cables. Included in this range are single core house wires, circular armoured and unarmoured cables, instrument and panel wires, and a wide range of other cables including flexibles for general and specialised applications.

XI. FUNCTIONS OF THE ENGINEERING DEPARTMENT

In the present facility, the main function of the engineering department is purely that of maintenance. Other functions include:

- Maintenance of existing plant equipment and buildings
- Rebuilding or reconditioning old plant and equipment
- Installation and alteration of plant equipment and services
- Installation of new plant and equipment

11.1 THE MAINTENANCE TEAM STRUCTURE

The maintenance work organisation is currently structured as follows.

- Central – three shift cycle
- Central – day shift only with standby artisans
- Parallel – workshop and production artisans
- Internal with other services out-sourced

11.2 USING CUSTOMER, SUPPLIER, AND EMPLOYEE SUGGESTIONS

To stay close to the customer, people should listen to the customer. Many businesses have a tendency to listen only when they are asking questions. They conduct surveys and focus groups, while ignoring unsolicited suggestions. If they are cheap to implement and carry little risk, put them into action. Once a company starts actively and quickly handling all the suggestions they get informally, and are looking for more, continuous improvement comes into the fold. In this way, small but irritating problems tend to be resolved immediately. Quality improvement is also faster, because the fine employees usually know of problems before managers do. Service or product issues may not be visible to a manager who does not spend time out front.

Part of the morale boost comes from employees’ feelings that they are respected. Part comes from having the power to immediately fix problems. That will also increase their commitment to the company’s business, because they will have a personal investment in it through their changes and actions; which will decrease turnover of the motivated, quality employees who are generally most sought after.

11.3 WORK ON THE OTK FURNACES

The major constraint on these is lack of available time by way of the availability of a maintenance window; the research suggests the following in carrying out an overhaul on the reticulation system for the OTK Furnaces:

- Poor pump delivery – It will be a good idea to overhaul all the pumps, one at a time - there are only three pumps, of which two are supposed to be working at any one time. The suction ball valves can also be replaced, since the current ones are old, and look suspect.

- Unconventional cooling design – The idea is to have the return water straight to the sprays at the top of the cooling towers,
implying a possible redesign of the whole system.

- As for the suspected poor filtration, the bypass valve that is suspected to be malfunctioning should be replaced, so that the cooling water passes through the filters. The filters also need to be redesigned so as to design out maintenance.

- With the high levels of scaling, rusting, and blockages, it is suggested that an RCM MSG or FMECA be carried out on the de-ionising plant.

- The pump filter mesh wire is just simply old and needs to be replaced.

Looking at the inductor pit, the problem of water gathering in the pit can be solved by levelling the pit floor or inclining it to the drainage side so that all the water can be drained out. This way the pit can be kept dry.

11.4 ARMOURER AND 37 STRANDING MACHINES

Whereas the target availability of these machines (97%) has been achieved, there is some time that is lost in setting up the machines. This needs to be dealt with so as to improve production on these machines. The starting point will be the designing or availing of a better loading system, manual or electronic. It will increase the operator’s motivation, and will have a positive bearing on the employee’s health. The concepts of externalising setups can also be considered.

11.5 SPARES FOR SCRAPPED MACHINES

These should be liquidated as soon as possible if found that they could not be used on any other machine. Keeping them means keeping the money tied up without earning any interest. If liquidated, the company will be in a position to release this money for other uses or investments. Less paper work will be another benefit for the stores department. The system will also be easy to monitor, hence more efficient.

11.6 OVERSTOCKED ITEMS

This is a sign of inefficiency on the stores and purchase departments. For those items that are not imported, and have a short lead-time, there is really no reason why the items should be overstocked, and that by over a hundred percent. Some of the overstocked items have been in stock for over 3-4 years; in some cases this is a sign that the items are slow moving, and hence the maximum stock level could be reduced, and some of the items liquidated.

Also, on the engineering side, it is necessary to look at spares that are imported, or have long lead times, and see whether they cannot fabricate them, thus utilising the available skill such as that in the tool-making department. The engineers can also work on redesigns of the components so as to make them readily available, and inevitably cheaper as an import substitution initiative. This will also go a long way in increasing machine availability, and decreasing breakdown time. Import charges are eliminated and lead times reduced. Employee motivation is improved due to the sense of self-dependency and accomplishment, as well as looking forward to the next challenge. Working on these overstock situations should also lead to realising cost savings, which is currently tied up in these spares.

11.7 UNDER STOCKING

This should be prevented at any costs. Stock items should be kept at their recommended levels, above the minimum required. This will in turn help the maintenance department by preventing unnecessary direct purchases, which might end up affecting the department’s budget. Down time will also remain low, meaning maintenance time will stay a minimum.

XII. ORGANISING FOR TPM

12.1 CONSULTATION BETWEEN WORKFORCE AND MANAGEMENT

An agreement to set up a steering group and to introduce first steps in Total Productive Maintenance process should be reached, any other business concerning TPM coming afterwards. Following this consultation, the two sides seek an agreement to set up a steering group and to introduce the first steps in Total Productive Maintenance process. At the end of these agreements, the whole company should be aware of these events taking place.

12.2 IMPLEMENTING TOTAL PRODUCTIVE MAINTENANCE

A typical TPM process should start with three key areas: policy and strategy, management and improvement of the organisation.

12.3 POLICY AND STRATEGY

Management needs to establish a mission statement, strategic corporate objectives, and a
business plan for achieving the TPM objectives. There also needs to be a visible and sustained commitment from every member of the business through personal leadership and example. Roles, responsibilities and objectives for each level of the organisation need to be established and maintained. These need to support the mission and corporate objectives.

12.4 MANAGEMENT

The next step requires planning to establish an effective organisational structure, establish, audit and keep under review an effective management system. The organisation will also need an effective, planned information system and a good communication system both internally and externally with suppliers and customers.

12.5 IMPROVING THE ORGANISATION

This means looking at the working environment, the measurement of performance, improvement objectives and plans, and monitoring and reviewing processes. The physical environment and relationship between the individual and the organisation and other employees should be structured so that each individual and team is aware of its contribution to the mission statement and the planned methods by which it can make improvements.

Improvement goals need to be closely integrated with the corporate objectives and should be considered separate to new capital intensive projects. Plans for improvement of product service, process quality, safety, environmental impact dependability and customer satisfaction are needed at all levels of any process.

It is important to ensure that all plans, targets and performance measurement throughout the organisation compliment each other and reflect the overall objectives of the mission statement, and help to review the results of improvement plans to obtain a measure of their effectiveness. Equally important is to have an effective reporting and feedback mechanism and structure.

An effective way of implementing TPM is through the use of small group activities. These are actually achieved by using three main Task Groups.

1. A management task group 1.
2. An engineering task group 2.
3. A production on task group 3.

Figure 1: Schematic TPM improvement process

The management task group will be responsible for:

- Formulating the TPM policy and objectives
- Selling the TPM philosophy to the whole plant personnel. The information should clearly describe the maintenance policy, TPM concept and why it is going to be implemented in the factory.
- Staff training.
- Executives and the Managing Director should show enthusiasm in the implementation of the TPM.
- Introductory Seminars to remove resistance to change are necessary.
- Formulation of a master plan is imperative.
- Kick off of TPM programme, usually in the factory greens, and attended by sister companies, suppliers etc.
The other Task Groups, 2 and 3 are responsible for:

- Defining current problems in their areas.
- Analysing the problem areas and bottleneck operations.
- Identification of every condition potentially related to the problem.
- Evaluation of the equipment, materials and malfunctions.
- Planning and investigating functions and malfunctions.
- Improving plant availability for both task groups 2 and 3.
- Implementation of autonomous maintenance for operators for task group 2.
- Increasing plant utilisation for task group 2.
- Autonomous maintenance can be achieved by using the five S’s or 7 Nakajima stages (Table 5) of step 8 in the 12 step TPM implementation plan (Table 5).
- 5S’s stand for Seiri (Organisation), Seiton (Tidiness), Seiso (Cleaning) and Seiketsu (Discipline), Shitsuke (Training). The engineering task group shall also handle training and education.
- Preventive maintenance, reduction of breakdowns through continuous improvements, spare part consumption reduction, maintenance for quality and reliability.

It is important to note that these groups are not mutually exclusive but have to interact. This is important especially on the implementation and reviewing of TPM performance as indicated in Fig. 1. The benefits achieved will form the basis of a Kaizen path (continuous improvement cycle).

Twelve Steps are considered for TPM development Programme:

Step- 1: Announce top management decision to introduce TPM. Details: Statement at TPM lecture in company, articles in company newspaper.

Step- 2: Launch education and campaign to Introduce TPM. Details: Manager: Seminars / retreats according to level. General: Slide presentations

Step- 3: Create organisational set up. Details: Form special committees at every level to promote TPM; establish central headquarters and assign staff.

Step - 4: Establish basic TPM policies and goals. Details: Analysis of existing conditions; set goals, predict results.

Step- 5: Formulate master plan for development. Details: Prepare detailed implementation for the five foundational activities.

Step- 6: Hold TPM kick-off. Details: Invite vendors, affiliated and subcontracting companies.

Step- 7: Improve effectiveness of each piece of equipment. Details: Select model equipment, Form project teams.

Step- 8: Develop an autonomous maintenance programme for operators. Details: Promote the seven stages of Nakajima involving the following to build diagnosis skill and establish certification procedure.

   i. Initial cleaning
   ii. Counter measures for the cause and effect of dirt and dust
   iii. Cleaning and lubricating standards
   iv. General inspection
   v. Autonomous Inspection
   vi. Organisation and Tidiness
   vii. Full implementation of autonomous maintenance

Step-9: Set up a scheduled maintenance programme for the maintenance department.

Step-10: Conduct training to improve operation and maintenance skills.

Step-11: Develop early equipment management programme.

Step-12: Implement TPM fully and aim for higher goals.

XIII. CONCLUSION

By looking at the maintenance significant items or machines out of the 27 listed it has been possible to detail some of the pertinent and attendant problems and then to proffer unique solutions to each of these problems for the critical machines. A broad based holistic approach is then suggested for the whole plant premised on implementing Total Productive Maintenance that is management led and steered by three groups that seek to have total
involvement of all players, major and minor, shop floor and white collar. Technically competent techniques such as the 5 Ss and Nakajima’s 7 stages of imbuing autonomy to workers are then used. It is the expectation of this paper that the readership will find parallels with their operations and use the material herein to stimulate adoption of a holistic and broad based maintenance approach to maintenance problem resolution and maintenance improvement itself.

REFERENCES

AUTHORS’ PROFILES
Kumbi Mugwindiri, did Bsc Mechanical Engineering Honours at the University of Zimbabwe, and Masters in Manufacturing Systems at Cranfield University, England. Currently, lecturing Engineering Management at the University of Zimbabwe.

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