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Research study on Dynamism of Checklist in Preventive Maintenance

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ABSTRACT

It is a known and proven fact that checklists can significantly reduce the risk of costly mistakes, standardize and regulate processes or methodologies, thereby improving overall working conditions. However their acceptance in various work environments is considerably low. To ensure that the work environment reaches desired performance level, there needs to be an effective and efficient preventive maintenance (PM) program. This PM program can be successfully executed with the use of a checklist which can be either paper-based, electronic or software based applications (electronic or software based checklist can be dynamic in nature). The dynamism in dynamic checklist system would bring in the desired changes in specific situations where a paper based checklist is being used.

Initially a thorough literature study on maintenance and checklists theory was conducted and the review was presented. Along with this the areas of lab testing and simulation testing methods were explored in order to find a way to test the dynamic checklist in a real scenario. Then a hypothetical preventive maintenance situation involving a production line using a static or a paper based checklist is considered at the beginning. To this preventive maintenance scenario, a dynamic checklist is applied and the changes observed after the introduction of dynamic checklist based more on process and context is significantly large. We also intended to study the dynamism in checklist and factors affecting the implementation in real life. From our inference we also suggest future work that can integrate the whole work flow and stabilize the system.

As a result from study we view the importance of dynamism of checklist and the factors that have potential for improvement has been highlighted. The concept of dynamic checklist has been introduced in preventive maintenance as means for improving working standards and reduces unforeseen adverse errors.

KEYWORDS: Maintenance, Preventive, checklist, dynamic

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ABBREVIATIONS

PM	PREVENTIVE MAINTENANCE
BCM	BUSINESS CENTERED MAINTENANCE
TPM	TOTAL PRODUCTIVE MAINTENANCE
RCM	RELIABILITY CENTERED MAINTENANCE
DES	DISCRETE EVENT SIMULATION

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1. INTRODUCTION

This chapter has the background to this master's thesis. In order to bring out the project idea, the aim of the project is more closely defined along with the research questions in order to make the reader understand better. This chapter concludes with the limitations of this master's thesis.

BACKGROUND

The objective of maintenance is to reduce the adverse effects of breakdown and to increase the availability at a lower cost, in order to increase performance and improve the dependability (schneider, November,2001). In order to fulfill the maintenance objective the company needs management skills to integrate people, polices, equipment, and practices (schneider, November,2001). Furthermore the company needs adequate technological and engineering skills in order to provide the best possible preventive maintenance, repair and overhaul of the ever increasing automatically-controlled production equipment. An effective maintenance policy is expected to reduce the frequency of service interruptions and many undesirable consequences of such interruptions (schneider, November,2001). Alongside, maintenance can be a profit producing activity rather than an unavoidable and unpredictable cost of doing business (Gelders, 1991).

Maintenance is carried out either as a planned (preventive) and unplanned actions in order to retain a system in or revert it back to its original settings (i.e. its operational condition). An optimal maintenance policy aims to provide optimum system reliability/ availability and safety performance at lowest possible lost (Hoang Pham, 1996). Preventive maintenance means all actions performed in an attempt to retain an item in specified condition by providing systematic inspection, detection and prevention of incipient failures (Hoang Pham, 1996).

The benefits of preventive maintenance are reduced probability of equipment breakdowns and extension of equipment life. The disadvantage of preventive maintenance is the need to interrupt production at scheduled intervals to perform the work (Swanson, 2001). The use of checklist in maintenance assists the maintenance operators to carry out their task correctly and effectively, thereby minimizing chances of making mistakes that can involve high cost and qualitative maintenance is enhanced. The checklist as such is a tool which prevents the user from making the errors, ensuring safety and leading to improved outcomes (Brigette M. Hales, n.d.).

As the stress and fatigue levels in human beings increase they tend to make errors. The cognitive function are often compromised with increasing levels of stress and fatigue during the complex, high fields of work (L.E. Bourne, 2003). Aviation, aeronautics and product manufacturing, where high level of perfection is needed, heavily rely on checklists to aid in reducing human error. Checklists are important tool in error management in all fields. They help in reduce mistakes which can incur high costs when unnoticed (Brigette M. Hales, 2006).

PROJECT IDEA

The aim of this project is to understand the usage of dynamic checklist in Preventive maintenance and study its implication when practiced in real time scenario, as in industrial environment. This goal is achieved by carrying out detailed literature research study relating to checklists. Furthermore, we try to implement a dynamic checklist over a static checklist in case, and understand the improvement in maintenance checks, prioritizing checkpoints, and human -user interactions and suggest potential areas for further research and development.

Additionally we tried to develop a lab set-up or a case scenario to test the dynamism of checklist, constructed based on a real time parameters. The lab environment or the case could be either a production line or a single machine. We intend to provide future works which can act as a base for continuation of this work to bring out the importance of checklist usage.

RESEARCH QUESTIONS

- What are the effects of using a checklist in preventive maintenance?
- How are dynamic checklists better than static checklists?
- What can be the ways of testing dynamism of a checklist?
- What can be the future development in dynamic checklists?

These are the research questions which we try to use in order to streamline the research and also by formulating these questions, we try to make the user to understand the theme of research.

DELIMITATION

The delimitations of this work are listed below:

- Maintenance optimization is not considered.
- Certain hypothetical assumptions are made in order to implement theoretical conditions.
- The checklist won’t be tested in industry and checked its performance in industrial level.
- This would be pure theoretical studies with conclusions drawn from literature studies.

2. RESEARCH METHODOLOGY

This chapter elucidates the methods used to answer the research questions formulated. The methods are formulated on the background of the material given. Firstly, the structure of the methods is presented, which shows the discussions and results are connected with the objective. This is represented using a flowchart given under this chapter.

There are two broad approaches to try and understand the collection of information for research: Qualitative and quantitative research. In this paper we have chosen a qualitative approach to support our case study research. The approach has the tendency to understand the phenomenon about which less is known mostly in context specific settings. The main purpose is to be able to explore, share and gather data from a variety of sources and research and validate the case with all the data available. A qualitative case study is the best answer to "how" and "why" questions.

A problem with choosing case study for your research is that, there is a tendency for researchers to answer questions that is too elaborate with too many questions and objectives. This can lead to difficulties in trying to reach a solid conclusion. This in the other hand can be avoided by placing boundaries on cases to prevent mishaps from occurring.

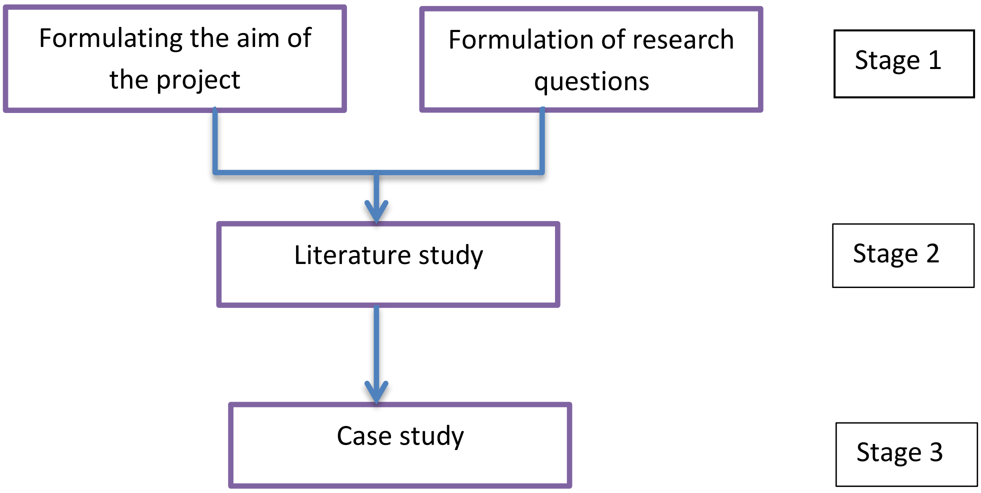

Fig1. Flow chart of methods

Following this is the presentation of the data collection used to gain knowledge in order to formulate the aim of the project and the research questions for the project. The remaining part of the chapter consists of the literature study with case study and lab-setup. Basically, the method involves three stages. They are explained below:

Stage 1

This stage consists of formulation of the project aim and research questions which evolves as the central theme. Aim of the project was streamlined towards the understanding of the implications of dynamic checklist in preventive maintenance. This helped to concentrate on a single goal rather than having more sub goals. Based on the project aim generated, 4 fundamental research questions were formulated that covered the aim completely and enable the reader to comprehend the purpose of the master's thesis.

Stage 2

This stage helped to collect data relating to the research questions. Starting with maintenance, deep understanding of maintenance definitions, different kinds of maintenance approaches and maintenance concepts were studies. Various search engines were used to collect information and Chalmers library was used to its full potential in order to get access to different scientific journals. Similarly, we did detailed research on checklists and checklist types; we explored the areas of simulation with an idea of testing the checklist in a production scenario, in order to understand the human behavior. Additionally, we also tried to learn about setting up a lab for practically testing the dynamic checklist tool.

Stage 3

A research case study is brought up in order to study the effects of dynamic checklist when used over a static checklist. According to Yin (R.K, 2009) Case studies have a unique advantage when trying to answer why and what questions about contemporary events over which the researcher has little or no control. Case studies are correctly understood as a particular way of defining cases, not a way of analyzing cases or way of modeling causal relations (Gerring, May 2004). This case study approach is attempted in order to connect the theoretical concepts with reality, which helps in understanding the experience and the real world.

A hypothetical case scenario is brought up where the maintenance operators use a paper based checklist system to carry out preventive maintenance tasks. An analysis of the current state is carried out and when on introducing the dynamic checklist the implications are drawn out based on the theory. And further they are discussed with the research questions in order to bring in deep understanding of the dynamic checklist. These descriptions fit the research questions of the performed research, which why case studies have been the chosen strategy.

3. THEORY

In this chapter different concepts and approaches in maintenance were reviewed in detail and the results from the literature survey are given below. Following the theory of maintenance, a deep reading was carried in order to gain significant knowledge on checklists, their types and importance along with studies on simulations and laboratory setup were carried out and are presented below.

3.1 MAINTENANCE

This sub-chapter consist of maintenance definition, maintenance related concepts and approaches.

3.1.1 MAINTENANCE DEFINITION

Gits (Gits, 1994)describes industrial maintenance as a "*process that helps the manufacturing process, in which the input is in terms of material and manpower, for example, is transformed into output, in effect, which are the finished products. Maintenance is a secondary/auxiliary process that contributes to the achievement of production*". "*Maintenance helps to mitigate/ to lessen the adverse effects of breakdown and increase equipment availability at low cost*".

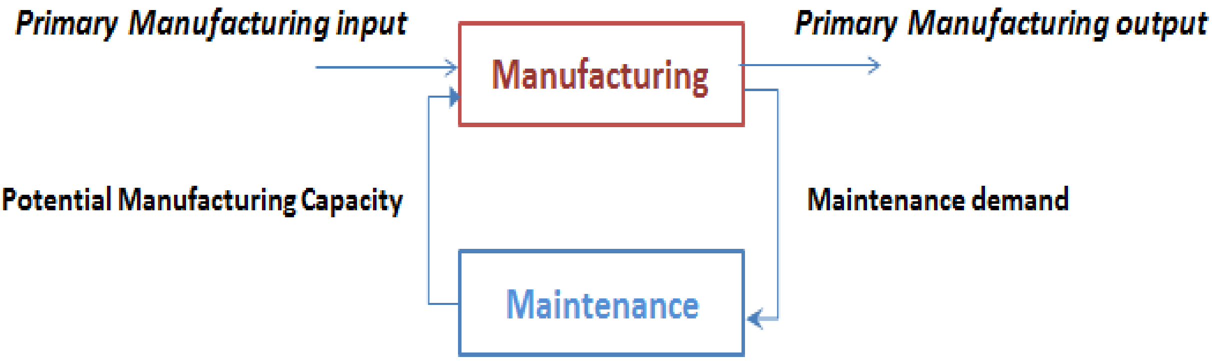

Fig2. Relationship between manufacturing and maintenance (Gits, 1994)

Simeu Abazi defines maintenance as " the key objective of maintenance engineering is to lessen the adverse effects of breakdown and to improve the equipment availability at a lower cost, in order to optimize the overall performance and alongside improving the dependability" (Simeu-Abazi, 2001).

Basically the manufacturing systems maintenance is done my implementing the formulated objectives pertaining to cost, delay and quality which are fixed by the direction of production, taking the risks of breakdowns and other factors into account. Holistically maintenance objectives are to ensure the systems availability, dependability and product quality along with enhancement of system life and safety (Simeu-Abazi, 2001). The following heading explains about the key maintenance concepts.

3.1.2 MAINTENACE CONCEPTS

In order to increase the effectiveness of maintenance and to focus the main activities, various concepts were developed. They are Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM), Terotechnology and Business Centered Maintenance (BCM).

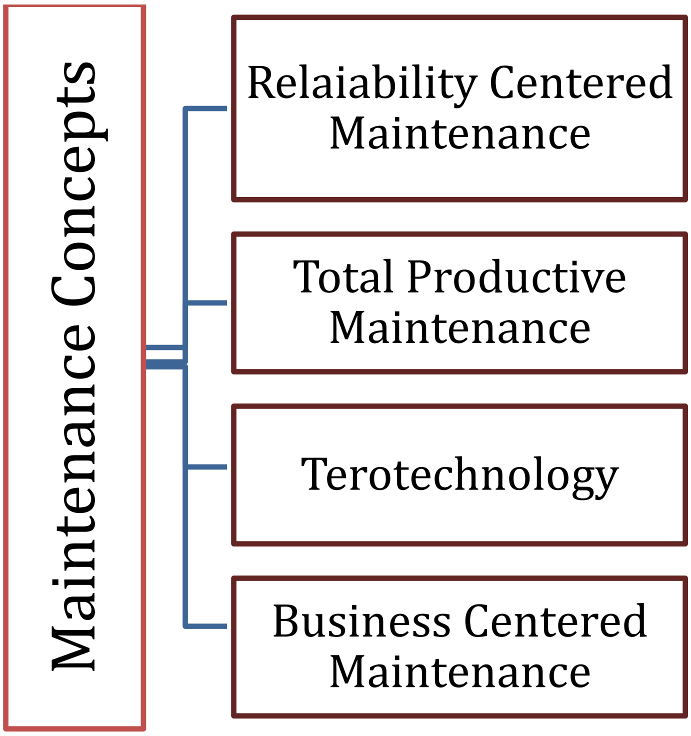

Fig3. Maintenance concepts

Total Productive Maintenance (TPM) brings maintenance into focus as a necessary and significant part of the business. It is no longer regarded as a non-profit activity. (Anon., 1996-2005)Down time for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process. The goal is to hold emergency and unscheduled maintenance to a minimum.

Seiichi Nakajima, vice-chairman of the Japanese Institute of Plant Engineers (JIPE), advocated TPM throughout Japan and hailed as the father of TPM (Kathleen E McKonea, January 2001). TPM was defined by JIPE as:

"TPM is designed to maximize equipment effectiveness (improving overall efficiency) by establishing a comprehensive productive-maintenance system covering the entire life of the equipment, spanning all equipment-related fields (planning, use, maintenance, etc.) and, with the participation of all employees from top management down to shop-floor workers, to promote productive maintenance through motivation management or voluntary small-group activities." (Tsuchiya, 1992).

Reliability centered maintenance (RCM) is another concept like TPM, whose main objective of RCM is to reduce the maintenance cost, by focusing on the most important functions of the system, and avoiding or removing maintenance actions that are not strictly necessary. RCM is a technique for developing a PM program. RCM was designed to balance cost and benefits, to obtain the most cost-effective PM program (Rausand, 1998). They were initially practiced in aircraft industries and military branches.

RCM analysis basically provides answers to the following seven questions (Rausand, 1998):

- *What are the functions associated with performance standards of the equipment in its operating context?*
- *In what ways does it fail to fulfill its functions?*
- *What is the cause of each functional failure?*
- *What happens when each failure occurs?*
- *In what way does each failure matter?*
- *What can be done to prevent each failure?*
- *What should be done if a suitable preventive task cannot be found?*

Terotechnology was initially evolved in Great Britain in the early 1970's. This concept stressed upon the vitality of linking between maintenance cost and feedback of information to plant designers. The application of terotechnology also takes into account the processes of installation, commissioning, operation, maintenance, modification and replacement. Terotechnology applies equally to both assets and products because the product of one organization often becomes the asset of another. Even if the product is a simple consumer item, its design and customer appeal will benefit from terotechnology, and this will reflect in improved market security for the product (Geert Waeyenbergh, 2002).

Business Centered Maintenance (BCM) is a framework based on the identification of the business objectives which are translated into maintenance objectives. This framework requires datasets on production plan, production process, forecast, and workload. The soul objective of this framework is to maximize the contribution of maintenance to great profits (Geert Waeyenbergh, 2002).

3.1.3 MAINTENANCE APPROACHES

Maintenance can be carried out using anyone of the following approaches or concepts. A flowchart is given to have concise view of the approaches. There are 3 basic types of maintenance strategies: reactive, preventive and predictive maintenance. Preventive and predictive are proactive strategies used to avoid faults in equipment thereby making it efficient (Swanson, April 2001).

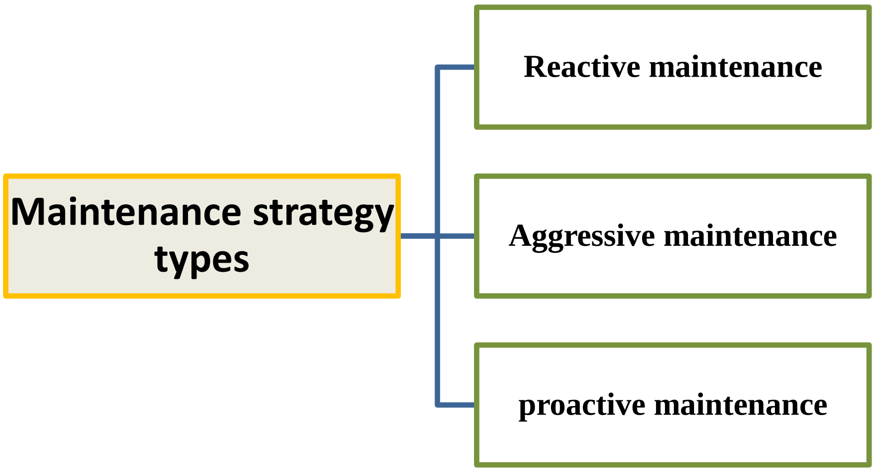

Fig4. Maintenance strategy types

Reactive maintenance strategy is a fire-fighting approach to maintenance (Swanson, April 2001). The equipment is utilized until the equipment reaches failure and then repair or replacement of the entity is carried out. Under this strategy, maintenance personnel opt for temporary remedy in order to make the equipment ready for the operation, thereby avoiding interruption (K Gallimore, 1988). The main advantage of the strategy is it reduces the maintenance manpower and the money that necessary to keep running the equipment (D.K Vanzile, 1992). The demerits of this strategy when practiced are unpredictable capacity fluctuation, high levels of scrap output and increased overall maintenance costs (K Gallimore, 1988).

The proactive strategy includes preventive and predictive maintenance strategies. The proactive maintenance strategy involves reacting well before the equipment fails, thus is done by monitoring the breakdowns in equipment. If any failure is detected, the equipment is attended and repaired well before the catastrophe.

Preventive Maintenance Program consists of actions that improve the condition of system elements for performance optimization and aversion of unintended system failure or collapse. It involves inspection, servicing, repairing or replacing physical components of machineries, plant and equipment by following the prescribed schedule. It is commonly agreed nowadays that preventive maintenance program can be very successful in improving equipment reliability while minimizing maintenance related costs (Anon., n.d.).

General objectives of any PM program would include the following (district, May 2010).

- Increase productivity by decreasing downtime
- Support the production facilities to operate at its optimal performance level.

- To create a safe environment by keeping all the facilities and components in good repair and condition.
- Helps in training and development of employees.
- Provide cost effective maintenance

Periodic maintenance is a strategy which takes service life as an important factor. The service life of the equipment is predicted based on inspection or diagnosis, so that the equipment could use until its end of life. Predictive maintenance is condition based and analyzes the data about deterioration of the equipment, and deploys monitoring systems to monitor conditions through online systems. (Anon., n.d.)

An aggressive maintenance strategy, like TPM, seeks to improve overall equipment operation. Maintenance may participate in these improvements through involvement in efforts to improve the design of new and existing equipment (K Gallimore, 1988).

3.2 CHECKLIST

Checklists are typically a list of action items or criteria arranged in a systematic manner, allowing the user to record the presence/ absence of the individual items listed to ensure that all are considered or completed (series, october 1999).

3.2.1 INTRODUCTION

Aviation, aeronautics and manufacturing firms started depending on the checklists in order to deprive them from making error. They are designed to function as information safeguards and protectors against faulty memory; hence checklists have evolved themselves in most fields aiding the practitioners to reduce the errors thereby improving the outcome. Checklists serve as a diagnostic tool providing a frame for valuation. As an efficient cognitive tool their ability to use the theories of category superiority effect where grouping relational or item-specific information in an organized fashion can help to improve recall performance (sharps MJ, 1995).

Many of the journals written regarding checklists were within the domain of aeronautical and aviation industries (Brigette M. Hales, u.d.). In these fields, where passenger and pilot safety is of high regard, they have adopted both paper based and electronic based checklist to enable them to minimize errors. There are normal checklists that are important for regular flights from pre-flight preparations to landing back again in the dock (series, october 1999). Checklists have evolved in the field of aviation maintenance for safety checks. The checklist may serve as a means to focus attention on the important information, the introduction of electronic checklist can enhance this effect.

3.2.2 TYPES OF CHECKLIST

There are different types of checklists; in spite they have at least one non-definitional function is that of being a mnemonic device. This function alone is useful in evaluation, since the nature of evaluation calls for a systematic approach to determining the merit, worth, etc., of what are often complex entities. A list of components or dimensions of performance of such entities is frequently valuable, and to judge from the results, even professional evaluators often forget key elements that should be included in systematic evaluations.

Checklists are of different kinds (Scriven, October 2005):

a) **Laundry checklist**- this checklist is a mnemonic device that the order in which one calls on the entity does not affect its validity. But the main concern would rely on entering the checkpoints under the correct category. Real laundry lists are not used for evaluation but most of them are used by evaluators.
b) **Sequential checklist**- the first kind of these where the sequencing (of some or all checkpoints) must be followed in order to get valid results. Example, pre-flight checklist, whose use is compulsory for the flight crew members who are carrying hundreds of passengers. This pre-flight checklist provides support for the evaluative conclusion that the plane is good enough to fly safely.
c) **A weakly sequential checklist**- the order is of some importance but for psychological efficiency reasons rather than from logical or physical necessity.
d) **Iterative checklist**- is sequential, in whole or part, but requires or may not require multiple passes in order to reach a stable reading on each checkpoint.
e) **Diagnostic checklist**- mainly used by taxonomists, mechanics and toxicologist. It supports classificatory kind of conclusion, as in the one that is descriptive but not evaluative, often the conclusions are evaluative.
f) **Criteria of merit checklist**- uses rating entries in a skating or barbeque or farm produce competition; it's what the evaluator uses or should use when rating the teachers researcher or funding request. It is often a tough item to develop and validate; it has to meet some stringent essentials that do not apply to similar types of checklist, as in it is vital that everything is complete in it and include every single criterion in it.

Checklist categories depending on the number of operators involved and extent to which the correct actions are verified (Bradford D Winters, 2009):

The main four principal types are:

a) **Static sequential with verification**- checklist involves a challenge and response. An operator reads a series of items and a second person verifies that each item has been completed or is within parameters. It is to ensure appropriate insertion of central lines is an example of this. As the physician performs the insertion, a nurse challenges the completion of each behavior/task and the physician responds to confirm whether the behavior/task has been accomplished.

b) **Static sequential with verification and confirmation-** checklists are used more often in team-based settings where a set of items/tasks are done by varying team members. A designated person reads the items (challenge) and each responsible party verifies the completion of their specific task. Time-outs and briefings in the operating room (OR) use this format. For example, the surgeon will state the patient's name, procedure, and surgical site and ask about availability of equipment (to which the nurse would confirm the information) and then ask about the patient's medical condition and availability of blood (to which the anesthesiologist would respond).

c) **Dynamic checklist-** Typically, there are multiple options to choose from and the care team must decide the optimal course (an algorithm). An example of a dynamic checklist is the American Society of Anesthesiologists difficult airway algorithm, which provides guidance on the intubation of a difficult airway. The team leader would use this algorithm checklist to develop a plan and then discuss it with other members of the team.

Checklists may be further categorized by their application to high-risk or normal operations. High-risk checklists are useful back-up plans to fix or mitigate harm when single or multiple failures of redundant systems occur. High-risk checklists can be used during a crisis to prevent further mistakes and to ensure reliable communication and operations. For example, their use during disaster relief efforts would standardize tasks and processes, thereby organizing different groups. Pre-operative preparation of patients is an example of a normal operations checklist.

Nature of checklists is given by (Shan Nan, 2014) are:

- Checklist in terms of process based, which are namely the collection of checkpoints or dataset pertaining to the checklist and priority between them.
- Checklist in terms of context, which are the condition related parameters of each checkpoints of the checklist.

3.2.3 Primary Objectives of any Checklist (Brigette M. Hales, u.d.):

- Aid the personnel in recalling the process of configuration or working procedure
- Provide a standard foundation for verifying the working procedure in order to avoid any reduction in working conditions
- Allocate duties to each employee in an optimum and well-coordinated work distribution inside the industry
- Provide a sequential framework that is able to meet the demands of both internal and external requirements.
- To serve as a quality control tool for the technical and management departments.
- It should allow mutual supervision among employees.

3.2.4 PAPER-BASED CHECKLIST

The usage of the paper based checklist had its own drawback of intense man based handling, it was very hard to be carried along the flight. Disadvantages of paper based checklist are: probability of getting lost while switching between the checklists is more and inability to mark skipped items, lack of pointer to current checklist item and many more are also possible. Hence in the Boeing 777 in the early 90s they have implemented electronic checklists which would guide the pilots during the normal and emergency conditions (Anon., n.d.). This intervention has considerably reduced errors by 46% as compared to paper based checklist (D, 2001).

3.2.5 DYNAMIC CHECKLIST

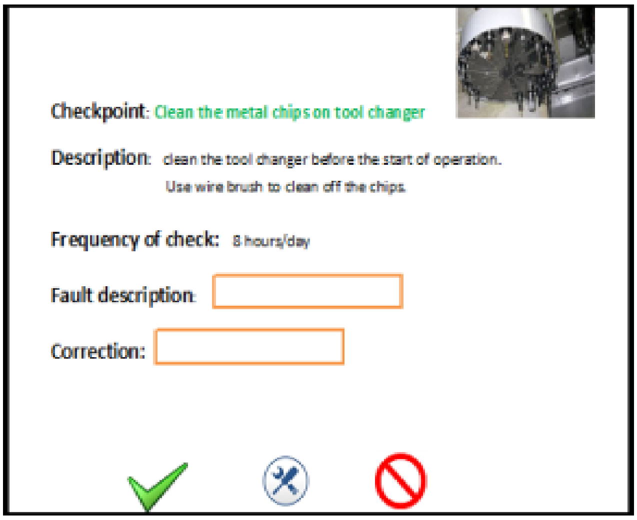

Fig5. Look-alike dynamic checklist

The above figure is an illustration of how a digitalized dynamic checklist can look. The checkpoint can be highlighted in some color, say green, which notifies the user of the current process. This helps the user to remember about the current checkpoint. While performing the checks, the user will be introduced to one check point at a time; this will eliminate the situation of skipping the checkpoints, lessens the user distractions, he can go to the next task only after finishing the current checkpoint completely. This checklist can eliminate the risk of producing costly errors.

At the bottom of the figure there are 3 symbols given, the one with a green color tick means **OK** which is clicked once the activity is performed correctly and can proceed further. The button with means **OK AFTER CHANGES,** if the checkpoint is not the same as given one, correct check is carried out on the machine and then rectified in the checklist, which gets updated automatically. Means **NOT OK,** maintenance operator if cannot perform the correct check on the machine this button is clicked. There are also spaces where function description of checkpoint, noting the error that is identified during the check along with its corrections is given.

3.3 MANAGING MAINTENANCE DATA

Checklist could be effective if it has sufficient and appropriate dataset for respective activity to be checked or carried out. In reliability engineering requires accurate and correct information to carry out the maintenance activity. In order to achieve such an efficient service, maintenance operators need to be supported with real time information about the machine status, current constraints in the production flow, and also substantiate with efficient guidance on how to solve the problems during critical repair condition (decision making system) (Z, n.d.) Some of the essential dataset for maintenance are processing times, mean time to failure, mean time to repair. These are some of the common parameters which every company would have in their data bases.

3.4 SIMULATION TESTING

Simulations are conducted for the same purpose of making better decisions (A.Seila, 1995).Improved decisions making attributes leads to immense benefits. When the systems are available or if it is not feasible to study, models are created to represent the relevant factors of the system and by restricting the problem to those factors reduces the complexity of simulation.

The 2 major benefits are increased efficiency and fewer costs- which would be the goal for any company. Some examples where simulations can be used are (ÄR Klingstam, u.d.):

- Predictions of systems performance
- Evaluation of a certain feature in the system
- Comparison Between Several alternatives
- Gaining Knowledge of the system at different life-cycle phases
- Problem Detection
- Presentation of predicted results.

The term simulation can be defined in many ways. T.Gogg and P. Pegden define it in a way that suits well for our project

"Simulation is the art and science of creating a representation of a process or system, for the purpose of experimentation and evaluation" (T.Gogg, 1993).

"…the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and / or evaluating various strategies for operating the system" (D.Pegden, 1995)

Some of the basic merits and demerits of simulations is (ÄR Klingstam, u.d.) :

Merits:

- Provides a solid base for decision making
- New situations can be explored
- Good knowledge about the system can be gained
- Experiments with time (lead,mean,cycle) possible

Demerits:

- Time-consuming
- Expensive software and hardware needed
- Scarcity of knowledge about simulation modelling
- Sometimes hard to analyze the results

A model which is nothing but a representation of the construction and working of some system of interest and a simulation of the system is carried out to experiment the model leading to results which are inferred. The main aim of the simulation modelling is to understand the properties concerning the behavior of the actual system or its sub-system (Maria, 1997).

In this type of study, Human decision making is very vital in model development, experiment design, output analysis and conclusion formulation the only stage where human involvement is not necessary is while running simulations. This is because simulation software packages do it efficiently.

There are 11 different steps that are necessary to develop model, design the experiment and performing the analysis. They are:

- Problem identification
- Problem formulation
- Data collection
- Design and develop the model
- Validation of the model
- Document for future use
- Select fit experimental design
- Perform simulation runs
- Infer the results
- Present conclusion

In spite of the model development, we need software packages that fit in our case to perform simulation. The software packages are chosen based on the analyst familiarity and cost (Maria, 1997) The present simulation packages require less programming, provides a natural ambiance for modelling, enhanced graphic and animation, flexibility to change the model and efficient auto backup (Maria, 1997)

There are 2 types of simulation packages: Simulation languages and application-oriented simulators. The former requires more of programming and offers flexibility while the latter are easier to learn and have modeling constructs closely related to the application (Maria, 1997).

Simulation in general and discrete event simulation in specific is been used widely in the field of production. Discrete event simulation simulates quantitatively representing the true model of the system under study, simulates on event-by-event basis and generates efficient reports.

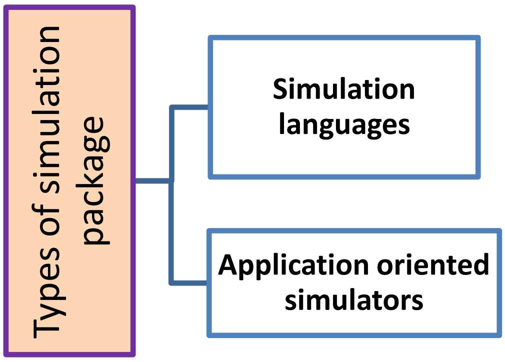

Fig6. Types of Simulation Packages

Table1. Benefits and pitfalls of simulation modeling (Maria, 1997)

Benefits of simulation modeling	Pit falls of simulation modeling
• Employ system approach to problem solving. • Experiment with new conditions for which the data available is less. • Test hypotheses about the system for feasibility. • Obtain better understanding of the system by developing a mathematical model of a system of interest.	• Invalid model • Erroneous assumptions. • Unclear objective. • Simulation model too complex or too simple. • Using simulation when analytical solution is possible. • Bugs in simulation program.

Table2. Simulation tools (Maria, 1997) (ÄR Klingstam, u.d.)

Types of simulation packages	Examples
Simulation languages	Arena, (DES Software), AweSim! (Previously SLAM II), Micro Saint *Object Oriented Software*: SIMPLE ++ *Animation Software*: Proof Animation
Application Oriented	*Manufacturing*: AutoMod, ProModel, Taylor II (DES software.

Simulations	*Communication*: COMNET III, OPNET modeler and planner. *Business*: SIMPROCESS, ProcessModel. *Health Care*: MedModel.

AweSim Language:

AweSim is a general-purpose simulation system which takes advantage of the latest in Windows technology to integrate programs and provide component ware. AweSim includes the Visual SLAM simulation language to build network, sub network, discrete event, and continuous models. Network models require no programming yet allow user-coded inserts in Visual Basic or C. Discrete event and continuous models can be created using the object-oriented technology of Visual Basic, C or Visual C++ and can be combined with network models (R, u.d.).

DES (Discrete event Simulation)

Discrete event simulation is a tool that is used for analysis of dynamics if discrete process in manufacturing system. DES is a powerful tool to check and analyze disturbances, their effects and propagation in a manufacturing system. With the DES working method it is possible to see what has changed when one disturbance is removed. The problem is in estimating the accuracy of the model and especially if the model is describing a nonexistent production line. Discrete event simulation can be used to understand the different component of failures in a production line of a plant (Arne Ingemansson, 2004). DES is used in the following areas: performance improvement of production process, making optimal operational policies and steps to improve production scheduling and planning (Ralph Riedel, u.d.).

In the next chapter, the hypothetical case scenario will be discussed followed by the results and discussion.

4. CASE

A detailed description of the hypothetical case scenario is drawn out in this this chapter.

Platen AB is a medium scale **production company located in Gothenburg, Sweden** which produces shafts, gears and many others for their local automobile companies. The company's efficient production process involves metal removing from the raw materials to give it the desired as per the requirements followed by the production of individual automotive components. The company supplies the produced components to Volvo cars, Volvo trucks, Scania.

Initially all the metal removing process was conducted by different machine tools like lathe, milling machine, drilling machine, boring machine, shaping machine, reamer etc. The preventive maintenance of these machines was done manually and more time was invested to complete. The company decided to purchase 4 CNC computer numerical control machines with 2 in each type like lathes and milling in order to replace the traditional ones. This helped them to carry out almost all the machining operations with the CNC machining centers to remove metal continuously 24 hours a day. They were able to carry out most of the turning operations such as facing, boring, turning, grooving, knurling and threading.

Since they had installed CNC machines in their shop floor replacing the obsolete their PM program had to be reconfigured. With the help of the line manager and the CNC operator, the PM checkpoints were discussed and updated in a static based checklist. A separate maintenance team of 5 fresh graduates who do not have prior knowledge about the CNC maintenance were employed for performing PM checks on the CNC machines. The main reason for employing them might be due to availability or may be to train them in different maintenance areas thereby capitalizing on their professional growth. Their responsibility included performing equipment overhaul at regular interval thereby preventing downtime of the line, most importantly preventing the failure of individual equipment components.

The checklist consists was a paper based checklist; some of the items on the checklist are optional depending on the needs. The activities on checklists are executed in a sequential order depending on the time interval. In case of faults or emergency the faults are rectified based on the experience of the maintenance personnel along with the help of the machine operator and the solution will be updated under the comments, so that it could be used in future references.

The line manager and operator conducted brainstorming sessions to pen down the check points of the CNC machines which would be given off to the maintenance team and the checklist for the CNC machines is Appendix.

The maintenance workers divide the work load among themselves to carry out the PM checks. For example, depending on the situation, either a single worker or 2 maintenance workers carry out checks on each machine. When 2 workers perform maintenance checks, the daily checks are divided equally among them to their convenience and PM is carried out. In case of emergency conditions, maintenance operator has to seek help from the machine operator to resolve the issue and update it under comments in the checklist.

5. RESULTS AND DISCUSSION

In this chapter we connect the results from the literature studies with the case scenario. The implications of paper based static checklist and digitalized dynamic checklist is explained.

From the above case, we can observe that the maintenance operators employed for the PM program of CNC machines has no prior knowledge about CNC machine. Hence they have to carry out their task with the help of the paper based checklist designed by the line manager and the operator. Initially, time for them to execute the maintenance checks might have taken longer as they have to figure out each and every checkpoint correctly on the machine. The checklist designed is basically a list of items or actions which are arranged in systematic order, to make sure that all items in the list are considered or completed. When a paper based checklist is in use in this kind of preventive maintenance situation it tends to drain the users motivation due to excessively long checklists and cause alert fatigues. Teamwork is not well supported in this type of format (Brigette M. Hales, 2006).

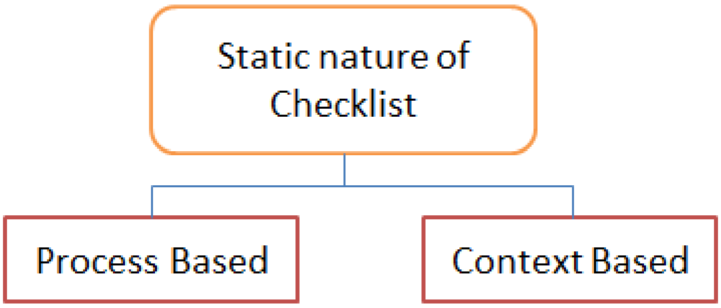

Fig7. Checklist Nature

The checkpoints given are static in nature in terms of process and context. Here in terms of process it means collecting checklist related items and the order between them. One of the crucial observations is that the division of user responsibilities is poor. This means, in this case, the operators did not allocate responsibilities properly; instead they divided the checkpoints based on their convenience. This might make the maintenance operators unclear about their roles and causes confusion eventually fail to perform checks when needed (Brigette M. Hales, 2006).

The checks should be carried out in an orderly fashion; they should not proceed to the next task without completing the current task. In a paper based checklist, the ongoing task status will not be highlighted; the operator should keep track of his on-going task. These type of checklists will fail to remind the maintenance personnel about the task which is been executed at present. The main objective of checklist serving as a memory recall is failed in case of paper based checklist. If the maintenance operator loses track of his current task, he might not complete the on-going task, might skip the task and proceed further. Thereby the worker will fail to complete his tasks which were allocated to him, in a randomized way. The paper based checklists used here did not pave the way for a standardized way of working.

Paper based checklists are static in terms of context, in other words machine specific data (like inspect oil magazine motor oil level, changing filters, check for hydraulic pressure etc.). In the current checklist, the most of the checkpoints are same for the machines without any variations regardless of if they need any different concerns thus making the checklist excessively long and redundant. During the emergency cases, the time invested for the preventive maintenance checks. Human error is unavoidable especially when under stress in high intensity work environments. This can lead to errors in judgment, decreased proficiency and increased risk factor. Checklist can have various objectives including memory recalling, standardization, regulation, providing a framework or as a diagnostic tool. However regardless of their purpose their main aim of their implementation is to have the best practice adherence and error reduction.

The checkpoints given the checklists are in a randomized fashion lacking prioritization. That is, the tasks are in a sequential order with important checkpoints in random places. For example from figure (), the PM checklist for CNC lathe, the checkpoints are arranged in a sequence or order but some checkpoints like check and maintain hydraulic pressure at 4.5 MPa, changing oil in cooler, inspect for crack in hoses, maintain oil temperature, checking lubricant levels that could be important as if these not properly checked might have great impacts on the work piece are arranged randomly within the checklist. These check points should have been given the major priority and the tasks should have been arranged in way starting from checkpoints of highest priority to the lowest ones.

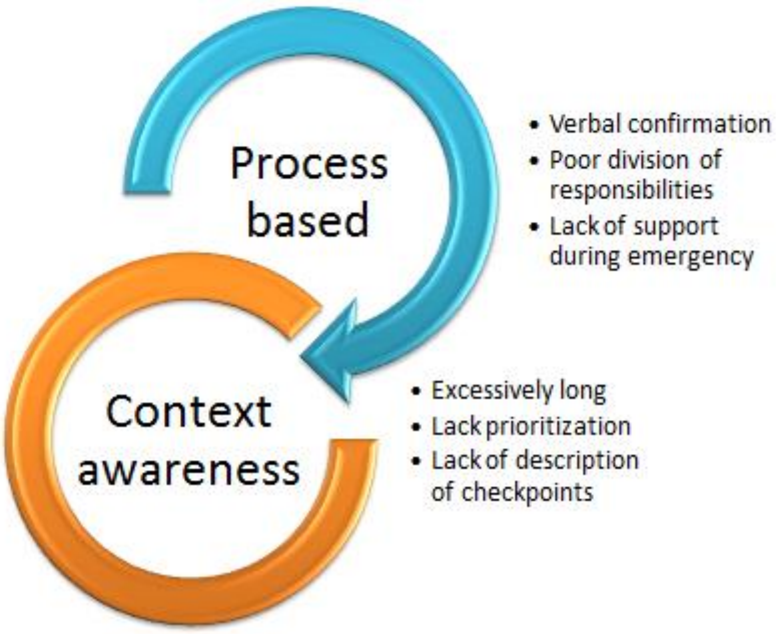

Fig8. Static issues

By doing these, the operator would know about the importance of each task and would execute them correctly with committing errors. In a case which involves time constraints, the maintenance personnel will execute the important ones, thereby saving more time.

Check for lubrication initial levels
Check spindle lube tube
Check air lubricators
Inspect for cracked hoses
Check for oil leaks
Check for hydraulic pressure and maintain at 4.5MPa
Ensure the chuck pressure is at right operating level
Inspect air filter, electrical cabinet
Change oil in oil cooler
Maintain optimum oil temperature
Check for abnormal force on headstock
Check tool knockout

Fig 9. Checkpoints

In industries such as production and manufacturing where the smallest error in the process could lead to big losses in manufacturing cost and have negative impact on the public, error management tool such as a checklist is vital. For areas in which there is a team of personnel for monitoring the quality of output, checklist is integral in ensuring proper operating procedures and quality standards are met. Maintenance personnel must use checklists at various stages to ensure that the products are up to quality regulations and also the overall manufacturing procedures itself achieves required standards for distribution to public.

The checklists for the CNC lathe and milling machines consist of both generic checkpoints (cleaning electrical cabinets, dusting the outer cabinet, power supply and voltage supply etc.) and specific checkpoints (In case of CNC lathe, some specific checkpoints are maintaining hydraulic pressure at 4.5MPa, checking tool magazine oil level etc., and for CNC mill some specific points are check for hydraulic counter balance pressure with respect to system specifications, check for air gauge for 85 psi etc.).

With both generic and specific tasks in the checklist make them long which can make the maintenance operator to lose interest and enthusiasm towards the completion of his check, thereby increasing the risk of making mistakes and incomplete maintenance work. Additionally the time for each check will not be given in a paper based checklist, hence the total time that has to be invested for the maintenance program will not be known. These drawbacks makes them unfit for complex maintenance checks on machines which has lots of checkpoints and for the fact these checklist will be very long consisting more than 5 pages.

The operator who carries out CNC maintenance lacking prior knowledge about CNC machines might find it difficult to identify the checkpoints on the machine and rectify them. To illustrate, checkpoint like checking for crack in hoses, here operator who doesn't have an idea of the main function of this checkpoint. This situation occurs because in a paper based checklist only direct checkpoints are given with no further explanation in brief about their functionality. If picture of the checkpoint function is not given it might be difficult for the user to locate who does not have idea about the machine. In this case since the operator hasn't seen a hose crack before it would be hard for him to judge.

Additional examples like in the PM checklist for CNC mill, the checkpoint inspect magazine motor oil level, does not give the information about what is the nominal oil level, without which it is difficult to check for the oil level in the tool magazine motor. Hence the execution of these checkpoints might need more investment of time as the operator might get stranded in the same checkpoint for long time searching for the location and will not know the exact functionality of the task.

Solving the static problem here is the key to develop a well-adapted checklist system which is dynamic in nature. Considering the current scenario, a dynamic checklist which is more process oriented and context aware would be ideal for solving checklist related issues. This system is implemented with the aim of reducing four types of errors that occurred with

conventional paper checklists. They are forgetting what the current item is, and thereby inadvertently skipping an item, skipping items due to interruptions and distractions, intentionally skipping an item and then forgetting to return to it and lastly stating that an item has been accomplished when it was not (Degani, u.d.). This dynamic checklist can be an electronic checklist system, or a software based application that be used in mobile devices.
The introduction of the dynamic checklist is to improve the adaptability and flexibility of checklists. During emergency condition, the dynamic checklist becomes adaptable enabling the user to make instantaneous changes in the checkpoints, along with adding error tags with corrections to those errors. The influence of dynamic checklist over static in any kind of system would bring in more transparency, traceability and accountability by tracking and tracing and showing list of tasks that have already been completed.

By analyzing and formalizing the process of action by being able to explore the chain of events makes human more effective, and a human interactive system more efficient and stable. Context based task filtering is achievable, tasks for a certain scenario or tasks that only a certain employee is specialized can be assigned avoiding excessive work load and by prioritizing the actions. For example, the maintenance operator is to conduct a daily maintenance on the CNC lathe, depending on the rating of checkpoints based on importance, the checkpoints are prioritized on the system, helping the person to concentrate on the important ones. Additionally, time for each operation can be given, enabling the user to know about the estimated for each task. With the help of the time data, the operator tries to accomplish the task within the stipulated time frame thereby saving overall maintenance time.

Data specific to the product and customer specific information could be added to the already existing data making the tasks more clear and specific. Another key problem solved with the introduction of dynamic over static is that a more process oriented approach could be implied by sending out more process aware information rather than a set of pre-defined items. Complex flows can be achieved especially in case of emergency or manufacturing fault where the line has to quickly undergo some crucial changes in order to still continue the smooth flow without much disturbances. Event driven activities can be assigned, in other words crucial tasks can be triggered by clinical events automatically and also focus on assigning the task only when the previous tasks are fulfilled thus making it less prone to errors and mishaps. In a human interactive work environment, team work and communication is of utmost importance. A dynamic checklist bridges the employees who work at different stations with communication by presenting a history of checklists or related information, emphasizing more on team work.

If the more lathe and milling machines are added into the current metal removing line more maintenance operator would be necessary to carry out the task. When they use paper based checklist, there is chance of confounding of activities. The same person can do the same task twice as they do not know who would be responsible for what actions. This can be eliminated when using a dynamic checklist. Using the dynamic checklist set of checkpoints can be allocated to each of the operators thereby improving the efficiency of the task.

From our literature research we understand the basic objectives of a preventive maintenance program in a work environment. Considering our case before the use of dynamic checklist, we observe that many unnecessary checks, repeated tasks and employees were unclear about the roles. With the introduction of Preventive maintenance including dynamic checklist, operations such as cleaning air filter, check for oil levels etc. can be removed from the daily checklist and performed when required thereby focusing on important checkpoints. For example, if the maintenance operator is working with internal moving components of the CNC, in order to enhance the safety of the operator, the dynamic checklist triggers automatic checkpoint to turn off the machine before working, without which the maintenance operator can’t proceed further. This feature in the dynamic checklist ensures the safety of the operators performing PM program as mentioned in the theory.

However questions have evolved over their ease of introduction into already existing work flow patterns. Although several process are well monitored , it is hard to implement an error management tool such as checklist as it comes with a hidden price tag of training challenges, unexpected error modes and unexpected confusions. The first relates to work organization. A checklist is used to improve communication, reminder under stressful conditions and this has a direct impact on the organization unlike other operational tools. Organizational changes are needed in the factory layout in order to synchronize the flow, in turn allocating the time required to effectively complete the checklist.

Human factors also come into play here as, unforeseen adverse events, unpredictable human factors can influence the approach of designing the checklist and implication of the checklist more complex. The other issue relates to cultural barriers or habits that exist at the workplace. For example, there is single maintenance personnel handling all the machines, when he uses the paper based checklists of all the machines it might be too hard for him to handle all the complex tasks of the machine during which he has to complete all the unnecessary tasks to complete the maintenance activity. Using a dynamic checklist only important criteria are highlighted for the current PM schedule and thereby making the tasks look simple to handle.
Under emergency situations or cases when the work pressure is reported high, use of checklist is an admission to lack of knowledge or skill and have can severe negative impact in a work environment. In some bigger firms, employees view checklist as a limitation to their judgment and decision making. Another added fear is that this tool can become dependent and limiting creativity in some cases.

The checkpoints like check for dust in filters, check and replace coolant filters, clean the spindle, clean the guide surface, application of grease in guide surfaces are some static checkpoints which do not vary much during the course of time. The checkpoints like maintain gauge pressure at certain level, maintaining oil level in servo motor, check for servo motor noise, vibration of headstock can change with time. These can be the dynamic checkpoints of the checklist due to its varying characteristic.

When these dynamic check points are monitored using paper based checklist, they become static by process and context. That is, the pressure variation monitoring would be difficult if the pressure has to be fixed to a particular calibration depending on the requirement, as the user would not know to which calibration it has to be fixed depending on the requirement. Whereas in a dynamic system makes it possible, for instance, under the checkpoint, maintaining gauge pressure at 4.5Mpa, additional details can be provided as to when a particular pressure should be maintained at 4.5MPa and when a pressure can be maintained between the range 4-5 MPa. These triggers can automatically be raised using a dynamic checklist assisting the maintenance operator.

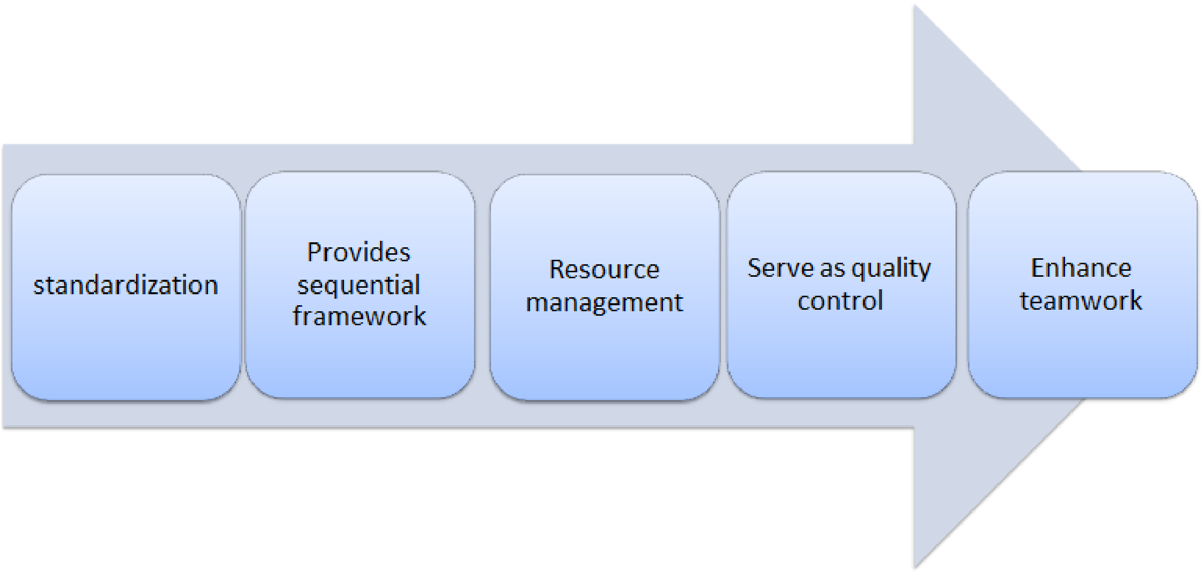

Fig10. Learning outcome

6. FUTURE WORKS

In this chapter, we try to suggest new techniques for improvements in the future, with the help of already existing technologies.

The scope for future work for dynamic checklists system is enormous considering their acceptance is significantly lower than expected. In this case, we can implement a Smart checklist support system, dynamic in nature, would increase the effectiveness of a human intensive system involving people , machines and software applications in which the expertise of the employee play a central role. By intense analyzing and formalizing of information and previous work data with the help of technology, we can explore and develop other human intensive systems such as air control, medical systems and plant management.

A good start would be to elaborate and analyze the existing process models, guiding the operators in real time in the form of checklists that alter and automatically adopt as steps in the process execution differs time to time. (Explain with the case some more lines)

With the introduction of a smart check support system, builds on the existing system to create and manage a dynamic checklist that is more context aware and profile based. The checklists will consist of context information ranging from history of previously accomplished tasks, summary and possible projections for future tasks. Checklist items will change dynamically as process is carried out, triggered by changes caused by actions of other task operators.

Most importantly the information collected from all these types of observation and monitoring will be saved to create profiles of tasks that have been completed and further expand process improvement. The system will use the context data to adjust the list of pending tasks dynamically therefore eliminating unnecessary steps and highlighting currently approaching deadlines, eradicate color coding and numbers and making tasks more clear. Analyzers are used to statistically determine the timing violations, to provide warnings early and to make sure deadlines are met in case of fault or emergency.

To achieve this vision the following areas need to focused on.

Deviation detection, Recovery and explanation.

The system is loaded with a set of predefined paths which is necessary for operators to complete their task. When a small deviation from the preferred sequence occurs, will guide and explain the reasons for the deviation and also suggest possible recovery actions. By monitoring the process or the sequence, smart checklist can compare the flowing sequence with all other possible execution that is described by the process model. If the conditions are not satisfied, smart checklist will notify a deviation and suggest the operators on how to recover from the deviation.

Context Awareness

Assists the task operators by providing the appropriate information of requests, in order to complete the tasks effectively. This is mostly important when some operators enter a particular process without much previous knowledge. Data deviation graphs (DDG) are used to manage such information. A DDG basically records all the steps performed, which operator performed it and observes types of inputs and outputs. By studying all the recorded information, expected future results and consequences from these could be understood. Another added advantage of information about future path is that potential resource allocation and elapsed time could be found out.

Profile based and Timing based analysis.

Accumulating historical information to determine if and when a particular check is wasteful because the circumstance that which the error or fault arise is rare. This is mainly used under conditions where errors hardly occur or on the other suggesting an extra additional check at a particular checkpoint. Real time constraints can be improved with a timer constraint.

By already using the existing technologies such as Docbox, Little –jil language, Janus message passing system and a multi-event processor the chain of events could be linked and more easily accessible. Little –jil is a specifically designed modeling language for evaluating process. While information is continuously exchanged and the processes are carried out with time, Janus could be used to translate the dynamically modified activities compatible with Little-jil language or vice versa using Docbox as a platform. When this system is paired with a multi-event processor, the dynamically changing information can be updated straight from the machine company's network, to all the personnel desktops therefore connection all the work station.

7. CONCLUTION

In this research we discuss the advantages and uses of checklist and stress upon change in the checklist design by replacing static or paper based checklist by dynamic/electronic checklist. General concepts of maintenance and checklist are presented in some sections.

The development of this research has led to two main issues in a paper based checklist: Static and Dynamic. Furthermore with the help of a case scenario, comprehensive view of issues in static checklist and impact of dynamic checklist is discussed.

We believe that with the proposed approach and introduction of electronic checklist will bring in significant changes in the work environment. As mentioned earlier approaches that are less flexible and comprehensive have shown some errors that can be rectified with the use of dynamic checklists and provides better cognitive support to operators.

There are several areas with improvement potential for future work. In this section we focus more on how to implement the dynamic system in the work flow. This future system can be implied in most work environments connecting all the work stations present and increase efficiency.

APPENDIX

Table 4: Preventive maintenance checklist for CNC mill

Preventive maintenance checklist for CNC mill			
Inspection	Status		Comments
	Complete	incomplete	
Daily Checks			
Check for orientation			
Check for axis reference points			
Check for lubrication initial levels			
Check spindle lube tube			
Check air lubricators			
Inspect for cracked hoses			
Check for oil level			
Check for pressure build during hand pumping			
Check for distribution film of oil on all sliding faces			
Verify lube operation			
Check for coolant level for every eight hour shift			
Ensure the chuck pressure is at right operating level			
Inspect air filter, electrical cabinet			
Clean chip from way covers and bottom pan			
Maintain optimum oil temperature			
Tighten the drawbar, holding devices			
Replace worn tool pump and motor			
Check tool knockout			
Check for heat and vibration of headstock			

Clean the spindle taper			
Test run the spindle			
Apply oil and clean spindle taper			
Inspect ATC			
Inspect magazine motor oil level			
Inspect magazine chain tightness			
Inspect oil level in APC gearbox			
Inspect the connections within the electrical cabinet			
Power supply, voltage			
Servo motor noise			
Check for backslash of ball screws			
Inspect cabling and connections of conveyors			
Clean chips from tool changer			
Inspect Cables			
Connections to machine			
Change Filters			
Change gear oil in Pump			
Check pressure settings			
Check entire machine for missing and loose fasteners			
Weekly			
Check and replace the spindle coolant filters			
Check for proper operation of auto drain on regular filter			
Clean the chip basket on coolant tanks			
Check for air gauge/regulator for 85 psi			
Have the hydraulic tank drained and replace the hydraulic oil with fresh hydraulic oil – also have the line filter and suction filter changed			
Clean exterior surfaces with mild cleaner			
If your machine is equipped with a cooling unit, have the unit			

drained and refilled			
Check for hydraulic counter balance pressure with respect to system specifications			
Check for breakage and thread damage			
Check draw bar height			
Check for the motor conditions			
Check limit switches and safety locks			
Monthly			
Check for oil level in gear box			
Inspect way covers for proper operation and lubricate if necessary.			
Apply grease on the outer guide of the tool changer			
Check side mount tool changer oil level			
Check for bust built up under electrical cabinets and clean them			
Replace coolant and thoroughly clean the coolant tank			
Check all hoses and lubricant lines for cracking.			
Clean electrical cabinets			
Check proximity switch operations			
Check for proper working for push button or rotary switches			

Table 5. Preventive maintenance checklist for CNC Lathe

Preventive maintenance checklist for CNC lathe			
Inspection	Status		Comments
	Complete	incomplete	
Daily Checks			
Check for orientation			
Check for axis reference points			
Check for lubrication initial levels			
Check spindle lube tube			
Check air lubricators			
Inspect for cracked hoses			
Check for oil leaks			
Check for hydraulic pressure and maintain at 4.5MPa			
Ensure the chuck pressure is at right operating level			
Inspect air filter, electrical cabinet			
Change oil in oil cooler			
Maintain optimum oil temperature			
Check for abnormal force on headstock			
Check tool knockout			
Check for heat and vibration of headstock			
Inspect ATC			
Inspect magazine motor oil level			
Inspect magazine chain tightness			
Inspect oil level in APC gearbox			
Inspect the connections within the electrical cabinet			
Power supply, voltage			
Servo motor noise			
Check for backslash of ball screws			
Inspect cabling and connections of conveyors			

Grease bearings			
Inspect Cables			
Connections to machine			
Change Filters			
Change gear oil in Pump			
Check pressure settings			
Weekly			
Check and grease the chain on the chip conveyor			
Check and clean the filters on the coolant tank			
Have the coolant tank cleaned of sludge, chips, and oil			
Have the chuck and jaws taken off the machine and cleaned			
Have the hydraulic tank drained and replace the hydraulic oil with fresh hydraulic oil – also have the line filter and suction filter changed			
Have the radiator cleaned and make sure the radiator fins are straight			
If your machine is equipped with a cooling unit, have the unit drained and refilled			
Have the lubrication unit drained and cleaned out – then add fresh way lube			
Have all way wipers inspected for any damage – clean and replace any wipers that are damaged			
Monthly			
Have the headstock checked for taper			
Have the spindle checked for radial and end play			
Have the chuck cylinder			

checked for run out			
Have the tailstock checked for taper			
Have the turret parallelism and inclination checked			
Have your distributor run a backlash program to check the backlash in X and Z axis and adjust if necessary			
Have your distributor check the X and Z axis gibs and adjust if necessary			

REFERENCES

- A.Seila, 1995. *Introduction to Simulation.* s.l., Winter Simulation Conference.
- Anon., 1996-2005. *The Plant Maintenance Resource Center.* [Online] Available at: http://www.plant-maintenance.com/articles/tpm_intro.shtml
- Anon., n.d. *An Introduction to Total Productive.* [Online] Available at: http://www.plant-maintenance.com/articles/tpm_intro.shtml [Accessed 7 28 2014].
- Anon., n.d. optimal maintenance models for system subject to failure- A review.
- Anon., n.d. todays electronicchecklists reduce likelihood of crews errors and help mishaps.
- Arne Ingemansson, G. S. B., 2004. Improved efficiency with production disturbance reduction inj manufacturing systems based on Discrete event simulation. Volume 15.
- Bradford D Winters, 1. A. P. G. H. L. J. B. S. J. R. P. J. P., 2009. Clinical review: Checklists - translating evidence into practice. *BioMed central,* 13(6), p. 210.
- Brigette M. Hales, P., 2006. The checklist—a tool for error management and performance improvement. 21(3).
- Brigette M. Hales, P. J., n.d. Checklist- a tool for error management and performance improvement.
- D.K Vanzile, I. O., 1992. Measuring and controlling machine performance.
- D.Pegden, R. R., 1995. *Introduction to simulation using SIMAN.* Blacklick, USA: Mcgraw-Hill.
- D, b., 2001. Todays electronic cheklists reduce lieklihood of crew errors and help prevent mishaps.

- Degani, P. E. a. A., n.d. *Electronic checklists: evaluation of two levels of automation.* San Jose, International Aviation psychology symposium.

- district, N. c. t., May 2010. *Preventive maintenance policies and plan.* [Online] Available at: http://www.nectd.org/
[Accessed 11 November 2014].

- Geert Waeyenbergh, L. i., 2002. A framework for maintenance concept development. 77(3).

- Gelders, L. P. a. L., 1991. maintenance management decision making. Volume 58.

- Gerring, J., May 2004. What is case study and waht it is good for. *The American Political Science review,* pp. 341-354.

- Gits, C., 1994. Structuring maintenance control systems. *international journal of operation management,* 14(7), pp. 5-17.

- Hoang Pham, H. W., 1996. Imperfect maintenance. Volume 94.

- K Gallimore, R. P., 1988. A framework for developing maintenance strategies. 29(1).

- Kathleen E McKonea, ,. ,. R. G. S. K. O. C., January 2001. The impact of total

- productive maintenance practices on manufacturing performance. 19(1).

- L.E. Bourne, R. Y., 2003. Stress and cognition: a cognitive psychological perspective.
-
- Maria, A., 1997. *Introduction to modelling and simulation.* s.l., State University of NewYork.

- R.K, Y., 2009. *Case study research, design and method.* 4 ed. CA: Sage Publications.

- Ralph Riedel, E. M. R. v. d. W. N. P., n.d. Integrating Human Behaviour into Factory Simulation - a Feasibility Study. *IEEE Xplore,* p. 2009.

- Rausand, M., 1998. Reliability Centered Maintenance. Volume 60.

- R, J. J. O. a. W., n.d. *INTRODUCTION TO AWESIM..* s.l., s.n.

- schneider, a. a., November,2001. present status of maintenance strategies and the impact of maintenance on reliability. Volume 16.

- Scriven, M., October 2005. THE LOGIC AND METHODOLOGY OF CHECKLISTS.
-
- series, U. s. a. f., october 1999. abbreviated flight crew checklist-USAF series.

- Shan Nan, P. V. G., 2014. Tracebook: A Dynamic Checklist Support System.

- sharps MJ, W.-L. C., 1995. relational and item-specific information as determinants of category superiority effects.

- Simeu-Abazi, Z. S., 2001. Maintenance integration in manufacturing systems:from the mode tool to evaluation. *International Journal of Flexible Manufacturing Systems,* 13(2), pp. 267-285.

- Swanson, L., 2001. Linking maintenance strategies to performance. 70(3).

- Swanson, L., April 2001. Linking maintenance strategies to performance. 70(3).

- T.Gogg, J., 1993. *Introduction to Simulation.* s.l., s.n.

- Tsuchiya, S., 1992. Quality Maintenance: Zero Defects Through Equipment Management.

- Z, K., n.d. Inspection Policies for Deteriorating Equipment Charaterized by N quality Levels.

- ÄR Klingstam, P. G., n.d. Overview of Simulation tools for Computer-Aided Production Engineering.