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INTEGRATED OPERATIONS PLANNING FOR ACHIEVING EXCELLENCE IN MANUFACTURING

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Abstract:

Competitiveness is an important issue for manufacturing industries in the present global scenario. An efficient planning of the production system will result in reducing the operational costs, which in turn have a positive influence on the business performance. The objective of this paper is to present the need for integrated operations planning in the present competitive scenario. The important issues of the production shop Floor Functions maintenance, quality control, inventory, production planning & scheduling, and the need for their integration have been discussed. The integrated approaches for these functions are presented along with the cost benefit. It is shown that the combined policy for the manufacturing decisions results in cost saving as compared to the independent planning, which further demands for the collaborative planning, as it can create coordination among the different manufacturing functions and smooth running of the organization.

Keywords: Integrated approach, operations planning, Maintenance, Quality, Scheduling

1. INTRODUCTION

In the present era of globalization, the business environment is continuously changing due to increasing global interconnectivity; ability to harness global resources, rapidly changing markets, increase in product-variety and concerns for product quality. To meet these requirements, the manufacturing companies are forced to automation and modernization of equipment, which in turn has raised the cost of manufacturing. In the current competitive industrial environment, the costs of operations and maintenance, as well as compliance with the production performance requirements, will be a decisive factor for success (Gao et al., 2010). Every manufacturing industry is facing the pressure of improving its performance for productivity, quality, cost, delivery of services/goods and customer satisfaction. To be successful, it is essential to improve the efficiency of manufacturing operations and reduce operating costs. A manufacturing industry can reduce operational costs by adopting cost effective production and improving the performance of its production shop floor activities. The objective of this paper is related to the interdependency between the important shop floor aspects like, maintenance, quality control, inventory, production planning, scheduling, etc. In actual practice, these shop floor aspects have an interacting effect with each other. For example, while production schedules are planned; it is assumed that machines are continuously available during production. However, in real life scenario, machines may fail and hence become unavailable for production due to corrective maintenance. If machine is not properly maintained, it may have a high failure rate resulting into lower availability and as a consequence, delay in delivery schedule. This may lead to inefficient production schedules, which may affect the efficiency of the production system and may lead to increased production costs due to increase in schedule penalty cost. Apart from this, a poorly maintained machine will produce more defective products resulting in large amount of rework and scrap. There exists a strong interrelationship between production scheduling, maintenance and quality control which is shown in Figure 1.

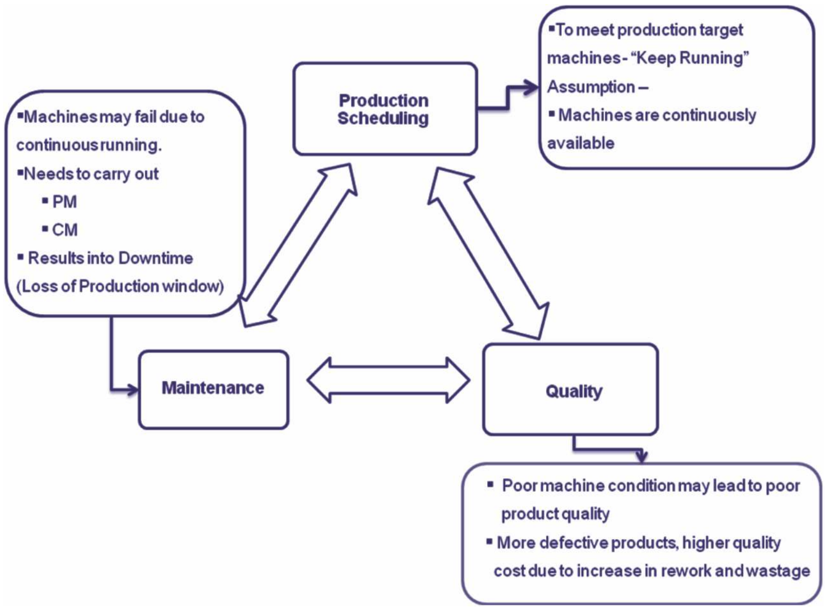

Figure 1: Interrelationship between shop floor functions

In the present manufacturing scenario, there are separate functional teams for planning and operation of the maintenance, quality and production scheduling functions. The decisions on these functions are taken independently for maximizing a function's performance and many times, the requirements of other functions is ignored. For example, a major shut down for maintenance may increase the machine availability but will affect the production schedule. Similarly, some of the component failures may not get detected immediately and lead to higher rate of rejections till the failure is detected. Hence, independent planning may improve the functional level performance but the overall performance at the production system level may get affected. Management usually looks at the production system as a whole and separate optimal solutions may not provide optimal solution for the whole system. Usually, there is a global optimal that includes all major functions in the production system. This global optimal can only be achieved by developing integrated models for all different functions (Hadidi et al., 2012). The Integrated models are expected to capture the interdependency between these functions and to avoid the conflicting situation. The integrated approach will result in significant savings in operational cost and improved efficiency for the production system. Integrated production models are expected to deal with multiple objectives with a conflicting nature. Hence, planning these elements independently will cause conflicts between these functions. This disturbance can be minimized through coordination to include two or more elements of the production system as shown in Figure 2 as an example of coordination in a real-life practice, where the output of one function is taken as an input for planning the other function.

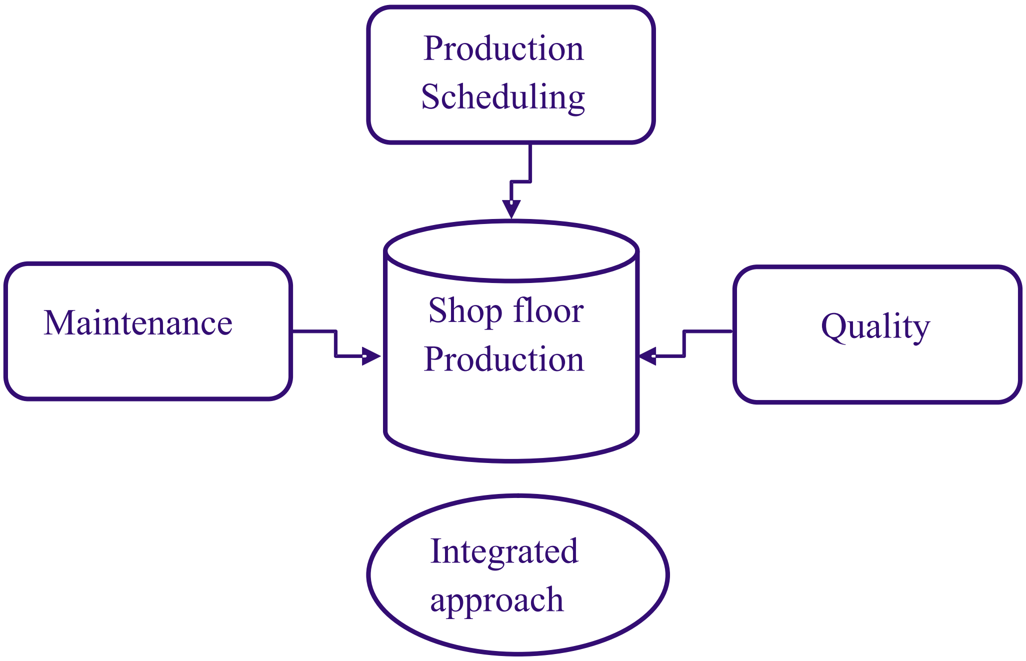

Figure 2: Coordination in shop floor functions

2. A REVIEW OF INTEGRATED APPROACHES ON MAINTENANCE QUALITY CONTROL AND PRODUCTION PLANNING AND SCHEDULING

To address the need for the collaborative operations planning, the integrated approaches between these function have been developed, which are discussed below.

2.1 Integrated Approach for Maintenance and Production Scheduling

Production scheduling and preventive maintenance planning are the most common and significant activities of the manufacturing industries. The role of effective maintenance planning is to achieve the desired operational objectives of maximum system availability, reliability and ensuring operational safety at minimum total cost. Maintenance activity can reduce the machine breakdown rate; however, inadequate maintenance of a system may lead to increased component failures during the system operation. Machine breakdown during production will result into machine being unavailable for production and thus the production schedule delays. This will further result into an increase in schedule penalty costs. Thus, there exists a trade-off between PM planning and production scheduling (Cassady and Kutanoglu, 2005). Despite the clear interrelationship between maintenance and production scheduling, in real manufacturing as well in literature, these two functions are dealt independently. In the recent years, there has been an increasing interest to develop the integrated models that take into consideration the joint effect of these functions in manufacturing systems. The number of papers published on the integrated approaches to maintenance and scheduling for different manufacturing systems since 1995 in a slab of 5 years is shown in Figure 3. From the Figure, it is observed that research on integrated planning have shown an increasing trend in recent years.

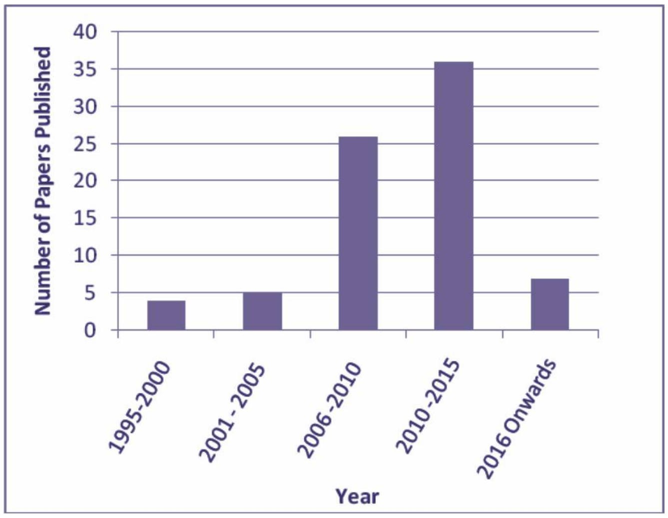

Figure 3: (a) Year wise research papers published on integrated approach for maintenance and production scheduling

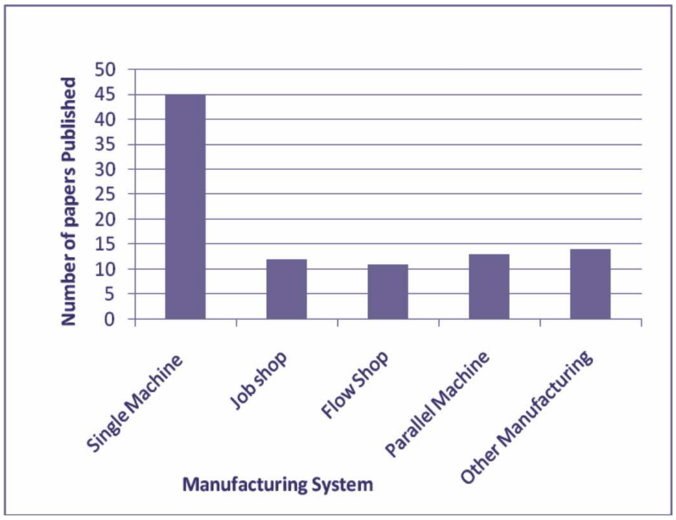

Figure 3: (b) For different manufacturing system research papers published on integrated approach for maintenance and production scheduling

2.2 Integrated Approaches for Maintenance and Quality

Maintenance is an important function to prevent machine failures; however, excessive maintenance results in unnecessary costs. On the other hand, if equipment is not well maintained, it may affect the quality and produce defective products resulting in large quantity of rework and scrap. The level of degradation of the product quality depends upon the deterioration of the equipment, which can be identified using the process control/monitoring schemes like control chart or acceptance sampling. Quality shifts result in poor quality outcome, higher operational cost and higher failure rate. Thus, removal of such quality shifts, besides improving the quality of the outcome and reducing the quality cost, is also a preventive maintenance (PM) action since it reduces the probability of a failure and improves the equipment reliability (Nenes and Panagiotidou, 2010). A suitable maintenance policy can improve the equipment performance and thus will help to increase the quality of products. It would therefore be appropriate to link statistical process control with preventive maintenance (Rahim and Ben-Daya, 2001). As observed by Ollila and Malmipuro (1999), maintenance has a major impact on efficiency and quality along with availability. In a case study carried out in five Finnish industries, they have observed that lack of proper maintenance is usually among the three most important causes of quality deficiencies in the process industries. Although, it is clear that maintenance affects quality, models relating maintenance to product quality have not been adequately developed in the literature and the integration of these two fields is yet to receive a significant attention (Xiang, 2013). The close interaction between maintenance and process quality have resulted interest among the researchers in the development of integrated models. The model allows the joint optimization of quality control charts (number of inspections, sample size, sampling intervals and control limit) and preventive maintenance level to minimize total expected cost.

The research papers on integrating maintenance with quality control since 1988 are shown in Figure 4.

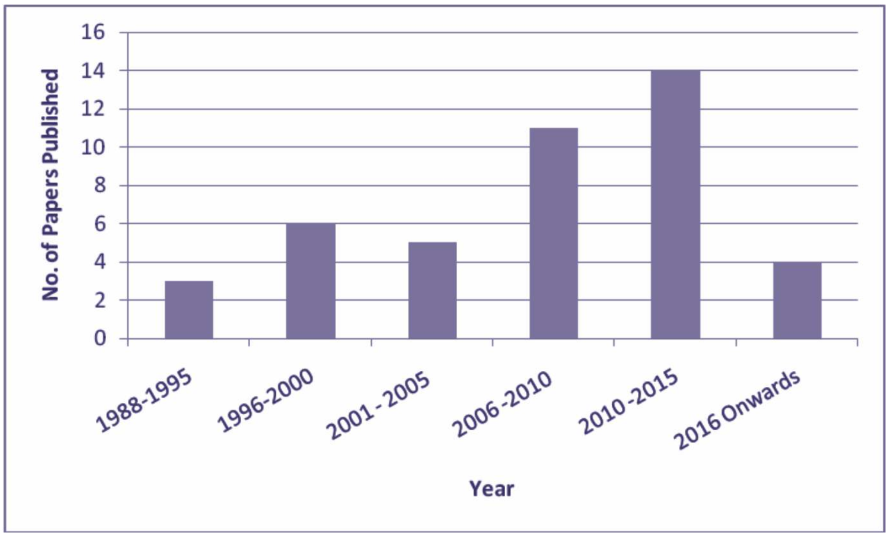

Figure 4: Research papers published on integrating maintenance and quality

Integrating these two management practices results into a coordinated Monitoring-Maintenance Model. In such a model, Statistical Process Control (SPC) monitors the equipment and provides signals indicating equipment deterioration, while Planned Maintenance is scheduled at regular intervals to preempt equipment failure. The determination of an unstable process, via SPC, results in an early Reactive Maintenance to restore the equipment. Otherwise a Planned Maintenance occurs after a specified period of operation (Linderman et al., 2005). The coordinated policy is depicted in Figure 5. The process starts in an in-control state and the process inspection occurs at the specified interval of production to determine whether the process has shifted to an out-of-control state. The quality characteristic is measured and plotted on a control chart to ascertain the state of the process to in-control or out-of-control state. If the control chart does not give any signal of process shift, then the planned maintenance occurs. However, if the control chart signals the process shift to an out-of-control condition and if the investigation of the assignable cause results in a valid signal, then reactive maintenance takes place.

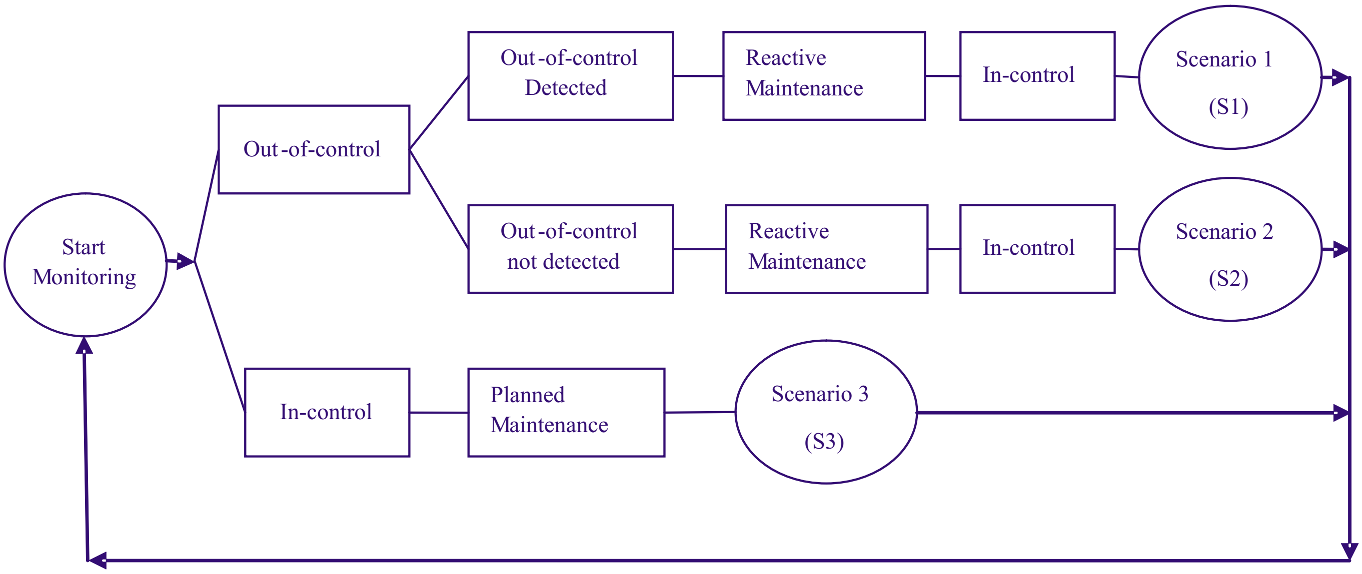

Figure 5 : Three monitoring-maintenance scenarios (Linderman et al., 2005)

Cassady et al. (2000) defined a strategy for monitoring and controlling a manufacturing process through the simultaneous implementation of $\bar{x}$ -control chart and an age-replacement preventive maintenance policy. This strategy is applicable for manufacturing processes where an out-of control state is due to equipment failure. They formulated a model which captured the costs associated with product inspection, process downtimes and poor quality. A simulation model was developed to analyze this economic model, and a simulation-optimization strategy was defined for evaluating the parameters of the control chart and the preventive maintenance policy. Their results suggest that the combined policy leads to much greater productivity as given in Table 1.

Table 1: Results of combining preventive maintenance and statistical process control (Cassedy et al. 2000)

Case	Control chart	PM policy	Estimated cost per hour
SPC and No PM	d = 1, n = 5, k = 3	none	2281.58
Optimal SPC and No PM	optimized	none	2260.80
No SPC and Optimal PM	none	optimized	2258.66
SPC and Optimal PM	d = 1, n = 5, k = 3	optimized	2211.14
Optimal SPC and PM	optimized	optimized	2193.09

Similarly many researchers have demonstrated that integrating the two areas has potential for reducing the operating costs associated with manufacturing processes.

2.3 Integrated Approach to Quality and Production Scheduling

As in most manufacturing processes, some products can be defective due to an unstable process environment, imperfect technology, low machine quality or human mistakes. Instead of being disposed of, defective items may be routed back into manufacturing process for rework. This kind of problem requires different sequencing rules for defective items to maintain product quality without increasing the completion time of the job schedules, and to ensure maximum machine utilization and minimize setup, rework and holding costs. Such problems related to scheduling of new and rework jobs on a single or multiple facilities have shown the link between production scheduling and quality. Inderfurth et al. (2007) have studied the problem of scheduling the production of new and rework items of the same product and manufactured on the same facility. The objective is to find batch sizes such that all demands are satisfied and the total cost due to setup, rework, and inventory holding is minimized. Polynomial time algorithms are presented in their approach to solve two realistic special cases of this problem. A generalization to a multiple product case is also discussed. Galante and Passannanti (2007), examined three different control policies to study the interaction between quality control and scheduling in a job shop environment. The control policies differ both in terms of the number of operations that are inspected, and with regard to the type of intervention carried out on detection of a defect. They observed that, each control policy affects the optimal inspection locations, which, in their turn, influence operation scheduling. MacCarthy and Wasusri (2001) considered scheduling as an activity within a process and have investigated the potential of applying statistical process control chart for monitoring performance. In this paper residual-based approaches and the exponentially weighted moving average chart are shown to be reasonably effective in avoiding false alarm and in detecting process shift. The feasibility of monitoring flow time in a single processor model using control charts is studied using simulation

2.4 Integrated Approach for Maintenance, Quality Control and Production Scheduling

The deterioration of the manufacturing equipment has an effect on both, production as well as quality. Very few papers have been reported to discuss about the interrelationship between the three functions.

Hadidi et al. (2012) provided a review on the models addressing different aspects of integration of production, maintenance, quality and inventory in the literature. They treated the integration approach in two different ways. The first way is to present models where a model is considered for one function taking into account the other. These models are referred to as interrelated models. The second way is to simultaneously model two or more elements of the production system, which are referred to as integrated models. In addition, they observed that integrated models represent a very specific life scenario that cannot be generalized to other environments, although some of the integrated models were mathematically elegant, they were not associated with real-life examples, some of them are so intricate that one cannot easily implement them, or some so strongly exploit specific features of the original studied problem that one cannot apply them to other problems.

Pandey et al. (2010, 2011) have hypothesized the interaction effect between the three shop floor level operational policies and developed an integrated approach considering the three functions. In the first paper, they have presented a literature review related to the integrated approaches for maintenance, quality and production scheduling and observed that even though maintenance decision has an impact on scheduling as well quality, integrated approaches exists for two functions only; either maintenance and quality or maintenance and production scheduling. They developed a framework for joint consideration of the three activities and an approach for integrating production scheduling and maintenance considering the

$$(CPUT)_{M/Q} = \frac{E[C_{PM}] \times E[N_{PM}] + \{E[C_{CM}]_{FM1} \times P_{FM1} + E[C_{CM}]_{FM1} \times P_{FM2}\} \times E[N_f]}{\text{Evaluation time period } (T_{eval.})} \quad (1)$$

Where, E[CPM]- expected cost of preventive maintenance, E[CPM]- expected cost of corrective maintenance, PFM-probability of failure mode, E[Nf]- expected number of failures, CPUT- cost per unit time. When the optimal schedule is implemented on the production line, it may be interfered by the maintenance department at optimal maintenance schedule interval. In order to implement both the policies, it is required to superimpose the maintenance interval on optimal batch schedule. Hence, for a machine processing three batches, there are four possible alternatives for superimposing the optimal maintenance schedule on the optimal production schedule. The superimposition is shown in Figure 6. The objective is to determine the optimal production schedule at which the CPUT of the integrated model is minimized.

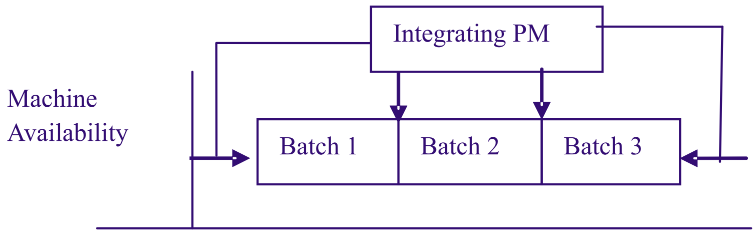

Figure 6: Gantt chart of production horizon showing different alternatives for superimposing PM schedule (Pandey et al., 2010)

$$(CPUT)_{S+(M/Q)} = \frac{\text{Total penalty cost due to batch and maintenance policy} + \text{Total raw material inventory carrying cost}}{\text{Schedule completion time}} \quad (2)$$

The results obtained using this approach for a set of problem are given in Table 2.

Table 2: $(CPUT)_{S+(M/Q)}$ at different locations of PM schedule superimposed in optimal production schedule (Pandey et al. 2010)

Batch Sequence	Location of PM	$(CPUT)_{S+M/Q}$
[B2-B3-B1]	PM is performed before first batch (in this case it is batch 2 i.e. B2	131
[B2-B3-B1]	PM is performed before second batch	263
[B2-B3-B1]	PM is performed before third batch	345
[B2-B3-B1]	PM is performed after third batch (no PM	837

In the integrated model, instead of obtaining the production schedule first, and then superimposing the maintenance schedule, the objective is to obtain the optimal schedule by evaluating the all possible locations in all possible job sequence. This approach is denoted as the integrated model S*(M/Q). The objective is to determine the optimal production schedule at which the CPUT of the integrated model is minimized.

$$(CPUT)_{S^*M/Q} = \frac{\text{Total penalty cost due to batch and maintenance policy} + \text{Total raw material inventory carrying cost}}{\text{Schedule completion time}} \quad (3)$$

The suffix S*(M /Q) indicates that the optimal production schedule is obtained by integrating production and maintenance schedule for a given control chart policy. Table 3 shows the calculation of (CPUT)S*(M /Q) for all the possible 24 iterations.

Table 3: (CPUT)S*(M/Q) for integrated model (Pandey et al. 2010)

Batch Sequence	*$(CPUT)_{S^*(M/Q)}$ at PM performed before first batch*	*$(CPUT)_{S^*(M/Q)}$ at PM performed before second batch*
[B1-B2-B3]	139	582
[B1-B3-B2]	131	587
[B2-B1-B3]	139	783
[B2-B3-B1]	131	263
[B3-B1-B2]	126	269
[B3-B2-B1]	**122**	236
Batch Sequence	*$(CPUT)_{S^*(M/Q)}$ at PM performed before third batch*	*$(CPUT)_{S^*(M/Q)}$ at PM performed after third batch*
[B1-B2-B3]	755	846
[B1-B3-B2]	754	833
[B2-B1-B3]	783	848
[B2-B3-B1]	345	837
[B3-B1-B2]	745	830
[B3-B2-B1]	349	825

3. A SUPERIMPOSITION BASED INTEGRATED APPROACH OF MAINTENANCE, QUALITY CONTROL AND SCHEDULING FOR MULTI-COMPONENT SYSTEM

In production systems, it is very important to ensure minimum interruptions (machine failure) during the production work to ensure maximum availability. This can be achieved with systems having reliable production equipment and/or efficient maintenance plan. The frequency of machine failures greatly affects the machine condition and hence, selection of an efficient and effective maintenance strategy is essential to achieve maximization of reliability, minimization of downtime, total maintenance cost and thus ensures a quick payback of investment on plant machinery. Maintenance plays a key role in minimizing equipment downtime, providing reliable equipment, improving quality, reducing cost and increasing productivity; as a result achieving organizational goals and objectives (Bashiri et al., 2011). Conventionally, scheduling of maintenance operations and production sequencing are dealt separately in industry as well as academia. In many industries, one of the main concerns is the large amount of money spent on equipment maintenance activities. With many equipments having multiple components used in the industry, after each working period, there is a break period that is usually used for maintenance actions. For example, the break time between two working periods in the textile companies, between two missions of the military war ship, between two trips of the trains, cars, etc. In general, the break period is not enough for maintenance of all components in the system, hence, only some components are selected for maintenance during that period. The purpose of selective maintenance policy is to help select a group of equipments for maintenance program so as to minimize the cost while keeping system availability at a specified level or to maximize system availability at a predefined maintenance cost rate. Selective maintenance is defined as, the process of identifying the subset of maintenance activities from a set of desired maintenance actions, which can be executed within the limited resources, such as time available, budget for the maintenance, etc. (Schneider & Cassady, 2004). For every component, one of the three actions namely, repair, replace or do-nothing is to be chosen. The maintenance actions (repair or replace) will improve the service age of the components. The integrated approach for selective maintenance, quality control and production scheduling is presented below.

3.1 Integrated Approach

In the S×M/Q approach, the schedule is optimized simultaneously along with the maintenance and quality control decision. The integrated approach is shown in Figure 7.

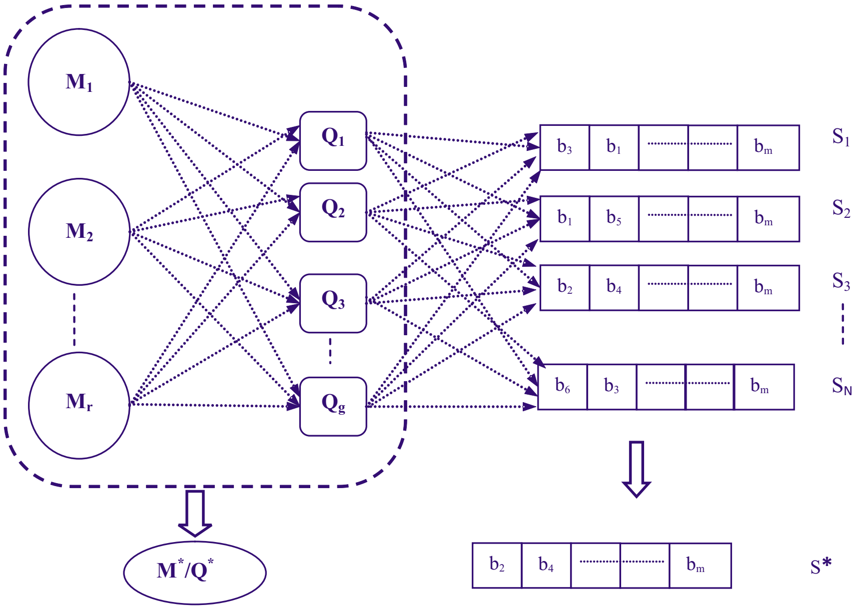

Figure 7: Integrated approach (Tambe & Kulkarni, 2014)

The approach works as follows:

As shown in Figure 7, the maintenance decision (M_1) is first combined with the quality control decision (Q_1). For each quality control parameter, i.e. sample size, acceptance number and sampling interval for the sampling based procedure, a range is selected and the quality control decision (Q) is the combination of these parameters from the range. Q_1 is any one of such combination of the parameters. The expected cost of the combined maintenance decision with quality (M/Q) is calculated. The M and Q decision are then passed to the scheduling algorithm i.e. Backward-Forward (B-F) heuristic, where the maintenance decision with quality is superimposed on each schedule generated during the iterations of the heuristic. For example, in the Backward Forward heuristic (Sule, 2007), the combined (M_1/Q_1) decision is superimposed on the schedule S1 to calculate the expected cost of the integrated decision of ($M_1Q_1S_1$). The batches are then swapped as per the heuristic rule to generate the second schedule S2 and the expected cost of the integrated decision ($M_1Q_1S_2$) is calculated. This is continued till the heuristic ends in schedule having minimum expected cost and the decision of (M1Q1S*1) is obtained, where S*1 is an optimal schedule found using M_1 and Q_1 decisions. Then another quality control decision (Q_2) is generated and the combined decision (M_1/Q_2) is passed to the B-F heuristic and the procedure of batch swapping to generate new schedules is performed as explained above to obtain the decision of (M_1Q_2S*2), where S*2 is an optimal schedule found using M_1 and Q_2 decisions. The process is continued for all the quality control decisions formed over the range selected for optimization. The optimal quality control (Q) and the schedule (S) is obtained for the maintenance decision 'M_1' having minimum expected cost.

The procedure as explained above is repeated for other maintenance decisions (M_2, M_3, …., Mr) generated during the iterations of the optimization algorithm to obtain the optimal quality and schedule for each maintenance decision. The near optimal values of the maintenance decision (M*), quality control parameters (Q*) and the optimal schedule (S*) will be based on the minimum total cost solution given by the optimization algorithm. The S×M/Q, in this way, is the full integration of the maintenance decision (M) with quality (Q) and production schedule (S). The objective of integrated approach is to find an optimal maintenance decision by taking one of the three maintenance actions namely, repair, replace or do-nothing for the system components along with the optimal parameters for sampling procedure namely, sample size, the acceptance number and the time between samples, along with the optimal production schedule.

Optimization Problem Formulation

$$\text{Minimize, } E[TC]_{Integrated} = E[TC_M] + E[TC_{PQC}] + E[TC_{PS}] \quad (4)$$

Subject to:

I) Total maintenance action time ≤ Available time for maintenance

ii) Availability due to maintenance decision ≥ Target availability requirement

iii) Detection time ≤ Limiting value of time to signal

Here, TC-Total cost, suffix M - maintenance decision, suffix PQC- Process quality control, suffix PS- Production scheduling.

3.2 Cost Benefit of Integration

A simulation model was developed to study the performance of integrated approach over the conventional approach. An example of 20 component system having repairable and non repairable components is considered for the study. The maintenance related parameters for the components are generated randomly. The model simulated 25 different cases of the effective age values of the components corresponding to the characteristic life (scale parameter, η) of the components. The problem of scheduling 10 batches is considered for the study. The percentage savings in the expected total cost for the integrated approach over the conventional approach of independent planning for the 25 cases is shown in Figure 8. An average 9-10 percent saving in total cost can be obtained for the integrated approach.

Figure 8: % Saving in total cost over simulation trials

4. INTEGRATING MAINTENANCE, INVENTORY, PRODUCTION AND QUALITY CONTROL

Production quantity, inventory, product quality and the maintenance are interrelated problems. A proper integrated production and maintenance plan can be achieved by optimizing the production rate and maintenance intervals for a production system. Each lot produced by the machine is subject to a quality control and according to the observed percentage of non conforming units found, one decides to perform or not maintenance actions and which type of maintenance to carry out. Production has to be stopped while the machine is submitted to preventive or corrective maintenance. In order to palliate these perturbations, a buffer stock is built up. A mathematical model is developed in order to determine the optimal values of both decision variables which are: the threshold level of the rate of nonconforming units on the basis of which maintenance actions are to be performed, and the size of the buffer stock. The optimal values are those which minimize the average total cost per time unit including inventory cost, maintenance cost and quality cost (Radhoui et al., 2009). Srinivasan and Lee (1996) modeled PM as a decision of the inventory level. PM operation is initiated when inventory reaches a certain level and it restores production system to an 'as-good-as new' condition. After the PM operation, the production system will remain without production until the inventory level drops down to or below a predefined value. At that inventory level, the facility continues to produce items until inventory is raised back to the inventory level where maintenance is applied. Ben Daya (1999) developed integrated model for the joint optimization of the economic production quantity, the economic design of x-control chart, and the optimal maintenance level to capture the interdependence between production quantity, quality control parameters, and maintenance level. It was observed that higher PM levels lead to more reduction in quality control costs. If the savings in these costs compensate for the added maintenance cost, the overall cost will be reduced compared to the no PM case. Ben Daya (2002) proposed an integrated model for the joint determination of economic production quantity and preventive maintenance level for imperfect production process. He proved that performing preventive maintenance gives way to a reduction of quality control related costs. Jiang et al. (2015) studied joint optimization of preventive maintenance and inventory policies for multi-unit systems subject to deteriorating spare part inventory. Results showed that the total cost rate to be sensitive to the maximum inventory level, which indicates that the research of this work is necessary.

In view of the strong link between production quantity, inventory, quality and maintenance, more research works needs to be attempted to catch their underlying relationship through a single integrated model.

5. CONCLUSION

Global competition in the market has created challenging environment to manufacture better product quality with tighter delivery requirements for customers, more profitability of shareholders, etc. To remain competitive in the market, companies need to maintain their competitiveness in terms of the cost, quality, delivery and service with their rivals. These business drivers make manufacturers pursue more competitive business models. The operational efficiency and effectiveness of the production functions are important to achieve the manufacturing excellence. The manufacturing, operations have interdependency between each other and the independent planning approach can result in suboptimal performance at the system level. This paper has presented the need for integrated operations planning to meet the competitiveness in manufacturing. The integrated approach between important shop floor functions; maintenance, quality control, inventory and production planning & scheduling has been presented. From the literature, it is clear that the joint considerations of maintenance, quality and production scheduling are gaining increasing attention from the researchers in recent years. The integrated approaches have shown more cost effective results as compared to the independent approach. The approaches will help industries to enrich the existing production planning decisions by integrating the machine availability arising from the maintenance decision along with elements from process quality control by taking into consideration simultaneously the possibilities of machine failure, process deterioration and restoration. This clearly shows that research in integrated operations planning has a great potential and in future more manufacturing functions can be included in the integrated operations planning to further contribute to more efficient planning and utilization of resources.

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