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# ICT-enabled integrated operations: Towards a framework for the integration of manufacturing- and maintenance planning and control

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**Abstract.** With the onset of increased competitive pressures from the likes of globalisation and various other factors, there has recently been a greater focus on the systematic integration of operations within and beyond enterprises. One such area has been the integration of maintenance planning and execution with the planning and control of manufacturing. Such a novel concept is denoted as Integrated Planning (IPL). In this paper we investigate developments within this area, and propose a conceptual framework which should be used to guide subsequent advances in the field.

**Keywords:** Manufacturing Planning and Control; Maintenance Planning and Control; Integrated Operations; Integrated Planning

## 1 Introduction

As the management of physical assets now accounts for a rapidly increasing share of operational costs, greater attention is being directed to maintenance thinking [9]. However, in the industrial environment, the relationship between production and maintenance has been conflicting in nature [25]. Nowadays, with increased global competition and decreasing profit margins, the need for an effective maintenance planning and control system is obvious. Yet maintenance often retains a negative image and is sometimes regarded as a necessary evil [4, 36]. As such, in companies that have production as their core business, maintenance is constantly subordinated to production, which otherwise consistently gets priority. This attitude is perpetuated regarding the planning and execution of each function. Though much time is spent on the production planning and control task, the most common maintenance strategy observed in business has been “we fix it when it breaks”. Fortunately however, maintenance thinking has more recently evolved towards the concept of World Class Maintenance (WCM) where the maintenance discipline is seen as a competitive advantage. For example in Oil & Gas industry, an observable trend is that maintenance is no longer comprehended as a necessary evil but a value-added discipline that has

considerable business impact [5]. Nevertheless, a common dilemma is the decision of whether to manufacture a product (which may result in the deterioration of the process) or to maintain the equipment for a possible improvement [14]. In order to resolve such a dilemma, the issue of integrating production planning and preventive maintenance is becoming an active area of research [2].

This article assesses the research gap between production and maintenance planning and control and further develops and proposes a conceptual framework for Integrated Planning (IPL). It is a conceptual paper and the primary research methodology is literature review. We take insight from both the maintenance management and production management domains and explore the possibilities for the successful integration of both disciplines. We identify important aspects and pertinent factors that should be considered when integrating manufacturing and maintenance planning and control, and develop a conceptual framework for such systematic integration.

The remainder of the paper is composed as follows: Part Two presents an overview of the relevant literature and discusses important elements from both production- and maintenance planning and control, before we develop and propose our conceptual framework for IPL in Part Three. We discuss our findings and limitations and draw necessary conclusions in Part Four, before finally present some areas for further research in Part Five.

## **2 Theoretical background**

The issue of integrated planning of production and maintenance is a recent problem [25]. For example, [8] state that maintenance management must be integrated with other functional departments such as production and quality control. A further challenge is the development of computer aided maintenance management (CIMM) systems that enable manufacturing companies to integrate, schedule and control production and maintenance. For example, though attempts have certainly been made to integrate the maintenance function into contemporary ERP systems [e.g. 27], any effort to integrate maintenance and production planning and control within ERP systems is lacking, at least to the knowledge of the authors.

Historically, there have been considerable efforts directed towards developing approaches that help increase machine availability by minimising downtime through more effective planning and control of maintenance operations [31], for example, Reliability centred maintenance (RCM) [28]; Total Productive Maintenance (TPM) [26]; and Risk-based maintenance (RBM) [15]. More recently, the concept of lean maintenance has become more popular [19, 35]. In order to support world-class manufacturing concepts such as lean manufacturing, several maintenance concepts have been developed. This has led to the concept World Class Maintenance (WCM) [29]. Similarly, the operations management community has also developed a variety of methods for improving manufacturing planning and control systems, such as the shift towards lean production [18, 38] and the onset of ERP systems [12, 13].

In fact, in both domains, issues of production modelling and maintenance modelling have experienced an evident success from both theoretical and applied view-

points. However, paradoxically, the issue of combining and integrating production and maintenance plans has received much less attention [1]. For example, *“Relatively few models combine production and maintenance scheduling issues”* [34]. In fact, Al-Najjar [3] states that *“of 140 papers surveyed, only eight made any reference to the integration of the manufacturing planning and control system with maintenance planning. In computer integrated manufacture (CIM) “everything” is integrated except maintenance”*. Yokota [40] performs a case study that examines the maintenance of ERP systems in Japanese manufacturing firms. However, this study does not consider the issue of production planning and control. Thus, it also comes as no surprise that ERP solutions with generic functional applications do not provide the full range of functionalities required for the planning and scheduling of complex maintenance tasks. In particular, current ERP systems lack the functionality needed for simultaneous planning and execution of both production and maintenance operations, including a lack of integrated data structures. In other words, *“existing data structures are designed for supporting individual techniques to operate in standalone mode with limited capacity for interfacing and integration”* [31]. In some (or even most) cases, even local systems rarely exist which can provide the data needed for such integration of maintenance management and manufacturing planning and control [33].

Faced with unplanned downtime caused by a production line failure, a manufacturer’s productivity is often significantly reduced, thus rendering the current production plan obsolete. The subsequent revision of the production plan in such an emergency situation is very expensive, and often has a detrimental knock-on effect on product quality and customer service level. [11] indicates that the common practice of making maintenance and production decisions separately can be rather costly and that there are significant benefits for making these decisions in an integrated fashion [8]. It is therefore essential that production planning and preventive maintenance activities are carried out in an integrated manner to hedge against such frequent yet avoidable failures and re-planning occurrences [2]. Though such integration is becoming an active area of research, it is frequently tackled solely at the operational (or scheduling) level. A case in point is exemplified in Malhotra et al. [21] where manufacturing planning and control is identified as both a strategic and tactical issue, yet maintenance is listed only as a tactical matter. On the other hand, [6] presents the maintenance management process as three tiers – Strategic (from business plan to maintenance plan); Tactical (from maintenance plan to task scheduling); and Operational (task completion and data recording). Such structuring can be likened to the three levels identified in the manufacturing planning and control (MPC) system framework of Vollmann et al. [37] - the strategic level of the planning system, which aligns the long term production plans with the overall business plan; the tactical level, which encompasses all decisions for detailed material and capacity planning; and finally, the operational level, which represents supplier systems and shopfloor systems (production activity control), and also includes performance measurement.

Though recent authors have developed models for integrating maintenance and production planning [e.g. 17, 39], such models have not been operationalized in practice [30]. Yao [39] contributes with knowledge for integrating preventive maintenance policies with shopfloor queuing systems in terms of production-inventory systems.

The limitation of this contribution is that it deals mainly with scheduling issues for operational decisions, leaving out both tactical- and strategic level decisions. Kovács [17] contributes with the integration of production planning and production scheduling. The limitation of this contribution is that only certain periods of planned maintenance are given, i.e. there is no real integration between maintenance planning and production planning.

### **3 Towards a conceptual framework for the integration of manufacturing- and maintenance planning and control: Integrated Planning**

Based on the previously described theoretical background and insights gained from our observations in practice, in this section we develop and propose a conceptual framework for the integration of manufacturing and maintenance planning and control, for which we use the term Integrated Planning (IPL). It has been shown in the extant literature that there is indeed a significant and positive indirect relationship between TPM and manufacturing performance through Just-in-Time (JIT), for example in the work of Mckone et al. [22]. Therefore, in developing such a framework for integrated manufacturing and maintenance planning and control, TPM from the maintenance domain and JIT and Lean production planning and control techniques from the production management literature could have been emphasised for application. However, when designing the roadmap to future maintenance it is not sufficient to solely implement TPM as a traditional concept for the business [32]. This view is also supported by Kodali et al. [16] where the shortcomings for TPM are elaborated. This leads then to the development of the world class maintenance (WCM) systems. Instead of relying purely on TPM, it is pivotal that the businesses can develop their own tailor-made WCM concept [32]. In order to belong to WCM it is important that the business develop and maintain future oriented tools such as Computerized Maintenance Management Systems (CMMS) with functions such as real time data input from assets and that this is integrated with other technical and business systems. Galar et al. [7] have proposed a future CMMS system and suggest that it be aligned with a performance measurement system such as that suggested by Muchiri et al. [24]. In this paper we have assessed current WCM-systems [e.g. 16, 23] and typical MPC system structures [37], and suggest integration as shown in Figure 1, which illustrates our conceptual framework for an Integrated Planning (IPL) system.

At the top level the business plan is outlined and consists of the production plan that delivers value for customers. This business plan is harmonized to both MPC and Maintenance Management. Functionality in the ERP system must ensure integration with both MPC system and Maintenance Management system. We also emphasise the importance of the performance measurement system in order to assess performance in line with the alignment of the business plan with integrated operations.

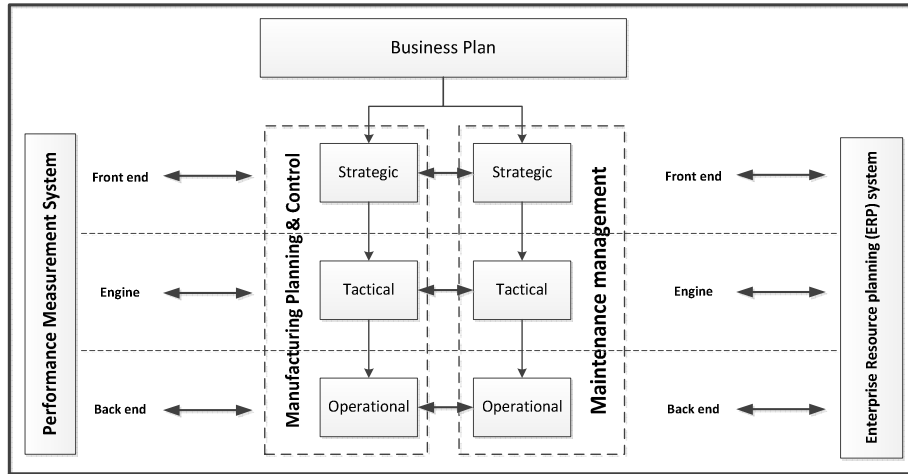


Figure 1: Conceptual Framework for “Integrated Planning” – IPL

It is anticipated the realisation of such an integrated planning framework would enable manufacturers to gain improved performance, particularly in terms of world class maintenance and OEE. For example, in using a more contemporary advanced planning and scheduling (APS) system tightly coupled with the company’s ERP system, a more accurate, integrated plan can be composed that makes important considerations regarding the maintenance activities as well as enabling improved finite plans for production. In turn, this will also influence a shift in thinking towards value creation, making such a framework well aligned with lean principles.

#### 4 Conclusion and further work

By combining relevant theory from two fundamental areas – production management and maintenance management – we have developed and proposed a conceptual framework for Integrated Planning (IPL). We position our contribution in Table 1, which has been adapted from Riezebos et al. [30] and Liyanage [20].

<1950	1950-1975	1975-2000	2000-2010	2010<
Manpower – Reactive; fix it when broken	Mechanisation – Preventive; Total productive maintenance	Automation – Proactive; Reliability-centred maintenance	Globalisation – Proactive; Risk-based maintenance	<b>Integration – Integrated; World Class Maintenance</b>
“Necessary evil”	“Technical speciality”	“Profit impact”	“Partnership”	“ Value-added ”

Table 1 – Maintenance in a time perspective [adapted from 20, 30]

The table illustrates the shifting role of the maintenance function over time, for example from the 1950s when maintenance was viewed as a “necessary evil” and was very much performed on a reactive basis, through the more preventive and proactive approaches deployed during the 1970s and 1980s and the focus on risk at the turn of the

millennium, to what we suggest as a more integrated approach in recent years. We believe that such an integrated approach will enable a greater focus on “value-added” as the maintenance planning and control tasks become even more tightly meshed with production planning and control.

Our conceptual framework should be used by researchers and practitioners to develop solutions that enable the systematic integration of “world class maintenance” planning and execution with “lean” production planning and control. We suggest that such integration will provide increased performance in terms of quality, cost and delivery metrics, and will generate enhanced competitive advantage of producers who are able to realise the integration of their critical operations.

In the mid-1990s, [33] pointed out that although computer-integrated manufacturing (CIM) systems encompassed the whole product cycle from design, through resource planning to manufacture, they did not encompass any maintenance. It was also stated that there exists a great gulf between the theoreticians and the practitioners which ensures that even the more practical operations research (OR) models are not widely applied. More than a decade later, Riezebos et al. [30] similarly identify a gap between the significant modelling efforts in theory (e.g. for the planning and control of preventive maintenance activities) and the limited application of such approaches in practice. Therefore, further work should address this gap. The existing efforts from OR should be developed into contemporary ERP modules to enable such integration of maintenance management into the manufacturing planning and control systems of today to become a reality.

In the future we intend to apply our conceptual framework to a number of case studies in order to gain important practical insight into the phenomenon of integrated planning. In gaining a better understanding of the practical challenges relating to the realisation of IPL, we will be in a better position to bring out the pertinent factors and implications for the design of a contemporary integrated production and maintenance planning system.

Also, though we have developed the IPL framework in the context of “land-based” production, due to the generalized and conceptual nature of our framework we anticipate that it could indeed be applied elsewhere, for example in the context of integrated operations in the petroleum industry, as the Integrated Operations (IO) Center is currently encouraging different disciplines and functions to shift from the traditional “silo” model to a more collaborative one [10].

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