An official publication of The North American
Institute of Science and Information Technology

ISSN:1923-0265

INTERNATIONAL JOURNAL OF Management Science and Information Technology

NAISIT
PUBLISHERS

www.naisit.org

The International Journal of Management Science and Information Technology (IJMSIT)

NAISIT Publishers

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This is one paper of
The International Journal of Management Science and
Information Technology (IJMSIT)
Special Issue: 2012 AEDEM Annual Meeting

NAISIT North American Institute of Science and Information Technology

The International Journal of Management Science and Information Technology (IJMSIT)
Special Issue: 2012 AEDEM Annual Meeting (99 - 99)

From lean to reconfigurability: systematic review of high performance manufacturing

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Abstract

Both the implementation of reconfigurable manufacturing systems (RMS) and its integration to current practices (e.g. human resources, information technology, etc.) being used within manufacturing plants are of fundamental concern to fields associated with business administration and management Hence, since specialized literature states RMS's effective operation will encircle lean manufacturing, this paper uses it as a foundation. While there has been significant study of lean operations, it is often piece-meal as diverse models are hypothesized and empirically tested. This paper attempts to examine the models purporting to study the fundamental question of the use of lean within a high performance manufacturing (HPM) framework. Models examining lean-HPM programs-performance relationship are summarized and reviewed systematically in an attempt to provide a more integrated perspective of lean and the factors that interact with it to enhance manufacturing performance to have a general representation of the HPM stage for RMS deployment. The models are evaluated on their common dimensions, and insights for further research are identified. A research plan, along with a research model, is proposed with the hope of facilitating future work in the implementation and operations of RMS, as an area of imminent and growing importance of having high responsiveness in ever changing markets.

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Keywords: Lean; High performance manufacturing (HPM); Just in time (JIT), Reconfigurable manufacturing system (RMS); Responsiveness.

1. Introduction

Reconfigurable manufacturing system (RMS), which is at the first stages of deployment, seems to be very promising to the point of being one of the logical steps in manufacturing. This is because it is developed to provide "reconfigurability" to manufactures, which gives exactly the needed functionality and capacity, exactly when needed, permitting reduction of lead time for launching new systems and reconfiguring existing systems, and the rapid modification and quick integration of new technology and/or new functions into existing systems (Koren et al., 1999; Yu et al., 2013); RMS plays an important role in the near future from the current point of view of lean manufacturing. However, it is very important to establish whether RMS is a new manufacturing practice, a program, a system, or just a new machine readily available to every plant. One reason for this is that if RMS is a new initiative, a plant must likely have to possess some special skill or capability when adopting it before its competitors do. Furthermore, after the first initiative adoption, if competitors are not to fall behind on their performance, they are then force to imitate. Because initiatives/practices are systemic, hence very complex, they cannot simply be acquired in the same way that a plant would acquire a new machine. The initiative's process of emulation is complex, and without any assurance of success, because they demand complex efforts and long periods for their implementation. Therefore, the differences between each plant's capabilities can prove decisive in determining the success, or failure, of the intervention undertaken. It is almost impossible for most plants to sustain the costs of investing in many areas simultaneously, so they must first decide what their priorities are and then choose (Filippini et al., 2001). In addition, once RMS is at the beginning of its cycle and only just beginning to be introduced as a practice, plants must not neglect it.

Within this agenda, it is being argued that RMS focus on new ways of designing and operating production systems by which plants will achieve cost-effective responsiveness (Koren et al., 1999). Therefore, future reconfigurable practices certainly promise to develop competitive value. However, for RMS to have competitive value as a manufacturing system, it must be supported by a foundation, which it is not secluded to the resource itself (reconfigurable manufacturing technology, RMT), but to the manufacturing practices (reconfigurable system) as a whole fitted in the plant. Furthermore, it must take into account the multidimensional nature of performance and the plant contingencies involved in adopting and implementing this practice (i.e., beyond the best practice argument).

Furthermore, as interest in RMS and its effect on competitive performance has grown, there has been a corresponding proliferation of research. However, all of the work on RMS seems to be characterized by having a limited focus, particularly with regard to viewing it mostly as a physical competitive resource. In addition, there seems to be no theoretical foundation for the proposition that RMS has a competitive value as part of a holistic structure within manufacturing plants. Studies pay little or no attention to contingencies (context) and linkages (both

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explained further below) involved in adopting and implementing RMS. Extant research does not pay enough attention to the wide multidimensional nature of the plant performance.

Besides, some authors argue that RMS will encircle lean manufacturing (Mehrabi et al., 2000; Bi et al., 2008.), and since lean is part of High Performance Manufacturing (HPM), this paper uses it as reference point. The concept behind HPM is to focus manufacturing in order to get global high performance, considering plant contexts. Likewise, HPM makes use of both, linkages among practices and continuous improvement. Plants, which adopt this philosophy, search constantly for opportunities to improve in key competitive areas, such as reconfigurability. Such improvements are essential in the company for its survival, benefit, and performance (Schroeder and Flynn, 2001, Ortega et al., 2012).

Thus, this paper proposes research questions as follows: are plants searching for performance dimensions related to RMS? Do lean and HPM programs have common practices? Is there relationship between common HPM and lean practices and performance dimensions related to RMS? Hence, the objective of this study is to identify conditions for future RMS applicability and implementation, summarizing HPM research, by drawing overall conclusions from many of past and current lean related studies. This paper uses an exploratory research, taking availability of HPM publications (both from the HPM international project and the OM literature in general) and the importance of the topic reconfigurability for OM, and applying a systematic review to lean-HPM programs (and their practices) and their impact on performance (especially responsiveness as a competitive priority).

An integrating framework is then presented to help to untangle the overlapping manufacturing practices of just in time (JIT), total productive maintenance (TPM), total quality management (TQM), human resources (HR), manufacturing strategy (MS) and technology (T) in relation to lean and performance. This is done by specifying a common set of lean practices that are shared or linked by those six programs. More specifically, the application of the systematic review is made with reference to two of the main steps towards the development of an empirically-tested theory of lean to outline current reconfigurable dimensions of performance being sought by plants and present context for future RMS practices (potential implementation by plants): testing both the adequacy of the measures and the linkages between them.

The remainder of the paper is structured as follows. The following two sections present a literature review first on HPM and the on RMS. Section fourth defines the constructs, develop the theoretical model, and conclude with a number of exploratory propositions. The analytical framework is reviewed systematically in the fifth section, where the current characteristics of lean manufacturing system and manufacturing programs are linked and some its practices classified according to HPM. Section sixth interconnects some key performance dimensions related to RMS to those practices and programs. The foundation of HPM about contingency and linkage is put as an emphasis to overview current manufacturing environments and practices where RMS may fit. The last section contains concluding comments and some suggestions regarding future research.

2. HPM: state of the art

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Back in 1984, Hayes and Wheelwright described for the first time the idea of competing by means of High Performance (Flynn et al., 1999). Ever since then, the idea has been used - sometimes with different names - by a number of authors during the past four decades (e.g., Schonberger, 1986; Flynn et al., 1997; Scroeder and Flynn, 2001; Ortega et al., 2012). By a careful analysis of high performers competitors from Germany, USA, and Japan, Hayes and Wheelwright defined the concept behind World Class Manufacturing as the base of the competitive strength of businesses in their capacity to design and produce superior products. In addition, once a high performance position has been reached, an emphasis of continuous improvement should be kept both in technical and in manufacturing capacities.

These two authors affirm that around the world well managed plants share many similarities (e.g. a well-managed Spanish plant is much more similar to a well-managed Italian plant than what the culture in Spain is similar to the culture in Italy. Furthermore, well managed Japanese plants have important similar characteristics to both such as quality, dependability, etc. (Schroeder et al., 2005).

Schonberger named such idea for the first time as “World Class Manufacturing, WCM”, when he wrote the first definite book about this subject in 1986. He expanded it in 1996 and 2001 according to contextual global changes. Unlike before, which was framed in competence terms, Schonberger sees WCM in terms of making things simple. However, they all view quick and continuous improvement as key element of WCM. Schonberger goes on defining the content of WCM with JIT, quality, employees' participation and preventive maintenance approaches, which are all focused to simplify and continually improve manufacturing systems. He perceives WCM as an important rearrangement of the complete manufacturing system, because simplicity is achieved by means of drastic reduction in material handling distances, reduction of setup times, reduction of lot sizes, quality improvement, use of preventive maintenance, and participation of workers and personnel staff in problem solution. (Schroeder et al., 2005).

In 1989, Hayes and his colleagues extended the idea from Hayes and Wheelwright back in 1984 to a dynamic learning framework, providing a theoretical base for infrastructure improvement. It incorporates improvements in control, learning, organization, material flow and people management in their relationship to manufacturing strategy. They define world class manufacturing as a sustainable competitive advantage in at least one dimension of manufacturing performance (Schroeder et al., 2005).

Later literature about world class manufacturing includes extensive tradeoffs/compatibilities studios in manufacturing performance (e.g. Ferdows and deMeyer, 1990; Filippini et al., 1998). They argue that it is not necessary to increase cost in order to improve quality or delivery times. Performance may be improved by the cumulative progression, beginning with quality and later expanding it to delivery, flexibility and finally to costs reduction, without experiencing tradeoff (Schroeder et al., 2005).

The most recent world class manufacturing literature has been expanded in an empirical form. For instance, Schonbeger (2001) published a book about his empirical findings in the USA. Many other empirical studios were

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made as part of the international research of High Performance Manufacturing (HPM), and the first 150 or so from this research have been published in a book titled "High Performance Manufacturing: Global Perspectives", edited by Schroeder and Flynn in 2001. This book argues that the methods of are not general purpose but rather they should be adapted to the local industry and the domestic environment for each plant. It also finds that the roads to reach HPM have been different in United States, Japan, and Europe.

An important contribution of the HPM research is the notion of the contingency approach, instead of only imitating the best practices from global competitors (Ketokivi and Schroeder, 2004). The contingency approach argues that HPM practices should be adapted and fitted to plants and their particular situations. Another distinctive feature of HPM is the emphasis placed on linkages among practices. It is argued that linking one practice to another is what leads to Word Class, and it is an ongoing need that must be continually renewed. It is not that success follows just from the number of practices that are implemented or from the latest practices, but from how they are related to each other and how they cumulatively build on one another. Linkages of practices provide the basis for binding new programs into what the plant is heading to. A great characteristic of the HPM research is that it is based on an outgoing well-defined and structured international database. So far, research groups from 27 universities from 11 countries have contributed to collect data from roughly 500 plants from 10 different countries from USA, Europe and Asia in three rounds. Another major message of HPM is that world class is an elusive target and with a high level of variation in plant performance. Therefore, it is necessary that a plant carefully diagnose its situation and then set out on a deliberate path of continuous improvement. Of course, this is easier said than done, leading to an explanation of why HPM is so difficult to achieve and sustain in actual practice (Schroeder et al., 2005).

To sum it up, it may well be said that High Performance Manufacturing is an integrated group of processes designed to reach world competitive advantage sustained by means of continuous improvement of manufacturing capacity (Schroeder and Flynn, 2001). As a dynamic manufacturing paradigm, HPM examines, at each moment of time, manufacturing initiatives for their possible inclusion as part of the manufacturing process, depending on the contingency of the plant and on the possible integration of the new initiative to what the plant is already doing, or is going to do.

2.1. HPM fundaments

It is necessary to define the meaning of "manufacturing initiative, practice or program". In this study, manufacturing initiative is considered to be an innovative action that modifies the managerial practices and the technological and organizational systems of a company with the aim of achieving the improvement of multiple performance types, and in particular, those of time, service, quality, and cost. In operation management literature, there is no one single definition of "initiative", since it is sometimes termed "best practice" or "technical and organizational innovation". Nevertheless, despite the variety of terms used, manufacturing initiatives show considerable homogeneity, to the point of being able to categorize them into only two main typologies (Filippini et al., 1996, 1998): initiatives of a prevalently technological character (e.g. CAD, FMS, etc.) and initiatives of a prevalently organizational character (e.g. human resource management, relationships with suppliers, total quality management).

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Through the implementation of manufacturing initiatives, plants can deal with the changing market environment. All manufacturing concepts have in common the fact that they interact with many plant functions simultaneously and cause significant change. Ultimately, the aim is to improve overall performance. There are a number of manufacturing initiatives documented in the literature, which aim for such an improved competitiveness. Management has the responsibility to choose and implement those concepts that are potentially capable of achieving manufacturing objectives. Many of these manufacturing initiatives may be made out of "bundles" of inter-related and internally consistent practices (e.g. HR: cooperation, training, turnover, etc.). In addition, some of these initiatives may be characterized as being part of other or others manufacturing initiatives (e.g. FMS as part of Manufacturing Technology). Depending on the particular requirements of the plant, there are different multi-dimensional approaches available that encompass a wide variety of these manufacturing practices in integrated systems such as lean production, mass customization, agile manufacturing. These systems could be distinguished from each other in various ways like, for instance, the number of initiatives undertaken, a propensity towards certain types of initiatives (e.g., hard, soft, or mix), the level of initiative penetration within the plant, etc.

The linkage idea that HPM stresses that JIT, HR, TQM, information systems, technology, NPD, SCM, TPM and other manufacturing initiatives should be linked together. In turn, all of these practices should be guided by manufacturing strategy to link the plant to its external environment. The external environment may consist of political, economic, social, and national forces. These environmental forces are in constant change and require adaptation and selection of the practices used by the plant to meet the changing situation (Schroeder and Flynn, 2001).

The internal linkage between practices means that they are linked together over time and that new implementations consider what has already gone before. As a result, the practices tend to reinforce each other and provide synergy. The linkage to the external environment can be thought of as the contingency approach that we discussed in the introduction. The paths followed to High Performance in different countries have varied greatly, thereby supporting the argument of contingency. The environment is a powerful force and cannot be ignored in selection and implementation of practices. A plant that has both a contingency approach for its initiatives and a well-integrated set of practices guided by an overall manufacturing strategy must be the foundation for the dynamic and never-ending path toward High Performance Manufacturing (Schroeder and Flynn, 2001; Machuca et al., 2011).

3. Reconfigurability: RMS and HPM

Beyond looking simply for the link between manufacturing programs, their practices and performance, the challenge in HPM should be justifying and examining why and under which condition any initiative or a set of them may have competitive value (Ketokivi and Schoeder, 2004). The competitive impact must be considered because the typical dependent variable in an initiative-performance study is some kind of competitive performance, whether it is operational (costs, delivery time, etc.) or financial (e.g. ROE, ROA) performance among the competition. Therefore, it is obvious that new technologies, products, processes, techniques, practices and systems are intensifying global competition among industrial companies, and in most plants is necessary a revision of the manufacturing strategy

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since each technology, process, technique, system, or combinations of them may be appropriate for different business environments. They can result in better performance if the key features are thoughtfully analysed and concepts are carefully adopted. The literature suggests that there are different ways to achieve the same results in different environments (Sahin, 2000; Knutsad et al., 2009).

To this, in most cases, manufacturing tendencies, unfortunately, are not necessarily universals. As a result, their implementation may be very complex and may require a great deal of resources, which would end up dissipating the real opportunities of the desired improvement. Many times, the effect of assuming the proposal of “one size fits all” may be of not achieving the conditions or requirements to get high performances, when for instance, a company takes the wrong path. Thus, during decades many companies have tried to improve their performance by launching many kinds of practices or initiatives, which have been successful in other companies (JIT, TPM, TQM, FMS, etc.). Even though when some progress is made, some companies have been disappointed with the results of some of these practices, and they have even concluded that these practices do not effectively work (Schroeder and Flynn, 2001).

In most cases, these initiatives apparently provide the most effective and efficient solutions to solve the problems of manufacturing operations, and they are well defined and contain in an extensive body of knowledge. However, the practical application of this body of knowledge with high performing results is something not easily found. Could it be that these techniques do not have what the company needs? It could be, but there is also a possibility that these techniques need absolute prerequisites for its effective application.

HPM is a moving target that requires constant attention and effort; the process is a ever-lasting journey. The truth for this is that every company is unique and the process to build a high performance business (one which consistently works fine over time) is more than applying every practice that turns up as a fashion. The groundwork for high performance must be designing constant and individually, according to the distinctive conditions of companies. This design is the planning and process of continuous improvement, where the company selects and modifies manufacturing practices (e.g. TOC, JIT, TQM, MRP, MRPII, ERP, etc.), which manage global high performance manufacturing according to its context, which may vary from country, industry, and size of the company, among other contingencies. Likewise, in this design, the existing practices must be linked together in order to get the objectives of the business. Ultimately, there is no long term sustained advantage, except the ability to continuously design for high performance (Schroeder and Flynn, 2001).

Historically, the idea with what most companies are familiar is recommending manufacturing managers to adopt every manufacturing initiative that appears as a tendency. This work, on the contrary, marks away from such idea, by associating to the company the concept exposed on the previous paragraph, whose focus is linking only the manufacturing practices (with or without adaptations) which jointly achieve a high performance organization. But before such linkage between practices, there must be a strategic plan of contingency based in the particular situation of the company, in order to select, adapt (when needed), and implement the practices, or the efforts of design will not have the desired effect (a more successful business). This process of contingence and linkage must be united

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with a deliberated path of continuous improvement. This approach is called High Performance Manufacturing (HPM).

The increment of world competition and the assessment that management approaches transcend national frontiers have created the movement of High Performance Manufacturing (HPM) in business and academic circles. This movement has revealed a necessity of higher integration of manufacturing process, human resources management and organization characteristics to achieve the objectives of world competitiveness by means of higher manufacturing management.

Throughout time, many companies have been in the advance party of the "best practices" in diverse aspects of Production and Operations Management. Their developments have nurtured the academic world, which in turn have been a focus for reprocessing and/or making knowledge to transfer to companies. However, using the concept behind HPM, this paper is not trying to establish the fashion of a new practice or program, but to focus manufacturing in order to get global high performance, considering the idea of contingency (each company is unique and special), as well as the linkages among practices and continuous improvement.

Thus, high performers should be constantly searching for opportunities to improve in key competitive areas. This should include reconfigurability, since such improvements in responsiveness must be essential in the company for its survival, benefit, and performance during these volatile times, especially due to the international financial and economic crisis.

3.1. RMS: from lean

The search to develop the technology for Reconfigurable Manufacturing System (RMS) increased in the beginning of the new century, as a cost-effective response to market demands for responsiveness and customization. According to Koren et al. (1999), RMS is being designed for rapid change in structure, including both hardware and software components, in order to quickly adjust production capacity and functionality, within a part family, in response to sudden changes in market. Koren and his coauthors assess that for a manufacturing system to be readily reconfigurable, it must possess certain key characteristics, which may include: i) Modularity of component design, ii) Integrability for both ready integration and future introduction of new technology, iii) Convertibility to allow quick changeover between products and quick system adaptability for future products, iv) Diagnosability to identify quickly the sources of quality and reliability problems, v) Customization to match designed system capability and flexibility to applications, and vi) Scalability to incrementally change capacity rapidly and economically.

New generation manufacturing systems will need new and effective tools to adapt to possibly frequent changes, new product introduction, and short runs without seriously impairing production. Thus, the motivation for introducing reconfigurable manufacturing systems is based on the belief that some economic benefits may be obtained by increasing reusability and reducing the excess capacity and/or excess functionality present in other types of manufacturing systems (ElMaraghy, 2006).

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Other authors such as Pham et al., 2010 say that in order to stay competitive, companies must possess reconfigurable engineering technology, which promises to make future RMS cost-effective and very responsive to all market changes. Furthermore, even when RMS still is not operational (least yet implemented in any company) the specialized literature seems to indicate that it will certainly become a “best practice” as soon as RMS is made available. As matter of fact, proponents of this approach (e.g. Koren et al., 1999) believe that future RMS has the potential to offer a better economic solution than present flexible automation (e.g. flexible manufacturing system (FMS)) by increasing the life and utility of a manufacturing system. Some authors, such as Rösiö (2012), even go further by also stating there will be much more flexibility in future RMS.

We could go on and on about reconfigurable technology potentials, but cautious should be taken when calling RMS the newest and surest initiative or manufacturing technology to get high performance for the near future, even if it is the subject of major research efforts around the world. Although technology may be available today to achieve a useful and affordable RMS, its cost effective responsiveness argument still needs to be verified. In practical terms, this means that, when taking into account the total life cycle of the whole system needed, RMS is more cost effective responsive over time than present flexible automation technology (see Koren et al,, 1999). In addition, there are at least 15 several fundamental and practical challenges remaining as open questions, which ElMaraghy (2006) lists as areas of research to complete the development of RMS.

Furthermore, even after RMS is operational (delivering the features it promises) there is still a fundamental question to answer: will RMS be a universal practice for all plants? The contingency argument, mentioned in this paper, has something to say about this question: it depends on the plant. Of course, this should not be an excuse for doing nothing. Therefore, as general literature suggests that global economic competition and rapid social and technological changes have forced the industry in general to face manufacturing responsiveness, what are WC manufacturers doing now globally to meet the requirements of responsiveness performance with available manufacturing practices? Will RMS help improving processes in any plant anywhere? Are all plants ready for RMS? These questions will serve as a guide for the rest of this paper.

Even if all industries were to experience ever-changing environments, it is very unlikely that all plants be forced, in the short term, to reassess their manufacturing programs, so that a new technology system such as RMS can be designed and operated efficiently. It will just not be feasible for all plants just to abandon many of their manufacturing programs in order to adopt this new manufacturing initiative. Moreover, as this paper has pointed out, there seems to be an unsolved controversy about the definition of RMS.

On the other hand, there are still other key issues to consider when implementing a new manufacturing program. For instance, Cua et al. (2006) assess that a new manufacturing program, such as lean manufacturing, TQ, TPM, etc., is introduced every five to ten years as the panacea for getting high performance. Furthermore, even when these programs fail in practice, the two main reasons given by many academics and practitioners are partial implementation of the programs and incompatible systems within the plant. Taking into account that most of past research primarily considers manufacturing programs in isolation, these same authors stressed the importance of

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linkages of manufacturing programs by implementing practices common to all existing programs and linking new programs with currently practices.

Therefore, as it has been said above, reconfigurable technology cannot be an end in itself since it has to be linked to other practices and areas of a plant in the path toward high performance. For starters, the pursuit of better performance and competitive advantage force manufacturing plants not to just obtain the latest equipment but to also develop resources and capabilities that cannot be easily duplicated, and for which ready substitutes are not available. Hence, in the context of the resource-based view (RBV) of the plant, HPM is more likely from: 1) internal learning such as cross-training and suggestion systems; 2) external learning such as customers and suppliers; and 3) proprietary processes and equipment; they are all developed by the plant to form such resources and capabilities. Hence, resources, such as standard equipment and employees with generic skills obtainable in factor markets, are not as effective in achieving high levels of plant performance. This is because they are freely available to competitors, and that internal and external learning play an important role in developing resources, which are imperfectly imitable and difficult to duplicate (Barney et al., 2011).

From some of the existing programs, this paper explores the literature of HPM to globally examine present conditions of plant contingency and practice linkages set in stage for reconfigurability. Thus, the starting point for this is the conceptualization itself of RMS one of its key issues: RMS literature sates that this new system has the means of improving the performance multidimensionality of lean manufacturing (Mehrabi et al., 2000). Therefore, taking into account the fact that lean manufacturing encompasses many of the HPM programs such as JIT, TPM, HR, TQ, technology, and manufacturing strategy, this is also another key issue to consider in the present paper.

According to Highsmith (2002), lean manufacturing is a management philosophy focusing on getting the product right the first time, continuous improvement efforts, quality in products and processes, flexible production, and minimizing waste from different sources such as in transportation, inventory, motion, waiting time, over-production, processing Itself, defective product (scrap in manufactured products or any type of business.). They also suggest that lean manufacturing has three underlying components: 1) delivering value to the customer; 2) being ready for change; 3) valuing human knowledge and skills. Since the literature relates RMS and lean manufacturing, there is a door open to regard the former as much more than hard technology.

3.2. Lean plant and reconfigurable plant

Although it may well be said that the reconfigurable context finds some support from some the essential elements from lean manufacturing or that some of it may somehow derived from lean, there are some clear divisions between the two.

Lean manufacturing is mostly seen as a simple improvement of mass production methods. RMS, on the other hand, tends to be breaking away from mass production, since it may allow the manufacture of highly customized products, when the customer needs them and the quantity required. In addition, while lean manufacturing has a production

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model capable of effectively operating when there are stable market conditions, it seems RMS is fit to face turbulent situations due to its high responsiveness characteristic.

Finally, the performance dimensions within lean manufacturing (LM), high efficiency and productivity, usually lead over the one of responsiveness (Hallgren and Olhager, 2009); however, as seen above, both, efficiency and responsiveness, are of equal importance in RMS. Thus, LM may be good for long runs, but, when compared to RMS, it is not as reactive and adaptable to the day-to-day affairs, or to the needs to industrialize a new product with short notices, or to adapting to a new demand. For this, the challenge is yet more agility, which may lead to reconfigurable processes that RMS seems prepared to deliver. Table 1 helps to illustrate some of the differences between present lean and reconfigurable plants.

Table 1. Lean plant vs. reconfigurable plant

(Adapted from Sahin, 2000; Borda, 2003; Marin-Garcia, 2011)

Lean plant	**Reconfigurable plant**
Very stable and big market	Unstable, uncertain, unpredictable and competitive market
Fixed and optimized lay out in flows and runs	Easily reconfigurable lay out, optimized in visibility
Small size lot production	All production levels
Technology of general use with parts of automation: fewer equipment with relatively flexibility, little polyvalence and medium-high production (including FMS)	Reliable and reconfigurable technology: more equipment with high polyvalence, less level of production and more parallel lines.
Balanced and synchronized operations. Continuous improvement (Kaizen). Reduced times of setup and equipment change. Reduced cycle time. Waste elimination. Lot size flow. Work cells. JIT	Reconfigurable manufacturing processes. No permanent manufacturing automation. IT usage. Continuous and radical improvement. Reduced times of setup and equipment change. Reduced cycle time. Economies of scale and scope
Automated manipulation to avoid personnel	Designed manipulation to do reconfiguration
Vision of assemble to order	Permanent objective of manufacturing to order
Quality, productivity and flexibility	Flexibility for unexpected changes (reconfigurability). High responsiveness speed
Component standardization to be able to standardize processes	Process alternatives to have reconfigurability
Statistics process control (SPC) from products to processes	Diagnosibility from processes to variable capacity, functionality and convertibility of product family
Restrictive product design	Open-ended system for future products and product changes
Set of manageable products	Product solutions based upon value
Integration of automated processes	Integration of semi-automated or flexibly automated but reconfigurable processes

Therefore, the context and practices differences between lean and reconfigurable plants are not that big if they are managed properly. In addition to the paradigms of contingency, integration, continuous improvement and dynamism, a lean plant (with non-reconfigurable equipment) may evolve to a reconfigurable plant if it has strived to do so by taking into account the following vital issues:

1. Less emphasis on high-automated processes by having more polyvalent and reconfigurable equipment: RMS.
2. More quantity of lighter equipment, and more parallel than monolithic lines to reconfigure the layout more easily. Modular installations of easy access and change: RMS.
3. Flexibility from beginning to end with very short change times from head processes to obtain high responsiveness speed: RMS.
4. Creation of a culture around alternative processes and not products.

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4. Framework definition

One important focus of management research in recent years has been linkages between manufacturing practices (e.g. Schroeder and Flynn, 2001; Ortega et al., 2011). Drawing on this, the study tries to find whether some current lean manufacturing practices are being implemented on path for RMS implementation and operation. Thus, in the search of competiveness and continuous improvement, the effective use of technological resources such as RMS should be essential for achieving a sustainable competitive advantage and for increasing the performance of the plant. However, although technology practices may in principle increase competitive advantage, it is necessary to analyze them in combination with the manufacturing strategy (MS) within plants, since there seems to be a clear influence between them (Schroeder and Flynn, 2001). For this reason, this paper stresses the need to investigate the combined impact of both sets of practices and performance.

Everything up to now has led to set a stage which may relate some HPM practices, from present lean manufacturing, in order to analyze future RMS manufacturing practices, using plant contingency, practice linkage and multidimensional performance. There are two main aspects of such a framework in the present study: 1) programs and practices of HPM programs; and 2) the effect of these programs and practices on performance. In this section, each component of the framework and the propositions are developed.

4.1. RMS and performance dimensions

Although traditional thinking has been that high performance in one capability is necessarily traded off for low performance in others, specialized literature shows this perspective is not that general. One reason for this may be the necessities in contexts of global competition and development and dissemination of advanced manufacturing technologies such as flexible automation, where the notion of trade-offs may be irrelevant due to the intensified pressures on plants to improve on all dimensions (e.g. Filippini et al., 1998). Furthermore, some authors, such as Boyer and Lewis (2002), use the term “cumulative capabilities” describing high performance in multiple capabilities simultaneously. Capabilities are described as cumulative because they build upon each other and are mutually reinforcing. The optimal sequence of cumulative capabilities is used here more generically to describe a situation where a plant has a high level of performance in more than one capability (Flynn and Flynn, 2004).

Establishing links between an initiative and performance outcome is, perhaps, the most critical and interesting aspect of a study on manufacturing practices, particularly when studying the situations, described above, where plants need to perform well in a multidimensional level. However, some existing literature still ignores the role of manufacturing goals and uses a one-dimensional performance measure in the models and empirical tests.

Following the above, in order to examine the relationship between initiatives and performance, this study focuses not only on the two performance areas from manufacturing, cost and responsiveness, which relevant literature (e.g. Koren et al., 1999) claims RMS will provide but also on quality, where all three are closely linked to plant operations. For the verification of the existing practices being followed by plants to get cost, quality, and

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responsiveness is necessary to identify the drivers of high performance and sustainability of these competitive priorities. POM researchers have contributed to the literature by examining the conditions under which specific practices, resources or structural arrangements are valuable.

Drawing on Kritchanchai and Maccarthy (1998)'s arguments that responsiveness supports quality, improves cost performance and can subsume speed, dependability and flexibility, this study uses the set of competitive priorities of quality, cost, speed, dependability and flexibility (Reichart and Holweg, 2007; Bernardes and Hanna, 2009; Wong y Evers, 2010). The last three priorities are being used as integrated parts of responsiveness. These authors assess that responsiveness not only covers them but addresses how to utilize and manage these performance areas in a purposeful manner. Moreover they noted that the level of responsiveness needed is different in every firm and depends on the individual business strategy, backing up the contingency fundament. All these five priorities of manufacturing performance (cost, quality, delivery/dependability, time and flexibility) represent one of most common approaches for performance measures (Ferdows and DeMeyer, 1990; Skinner, 1969). The priorities are briefly summarized in Table 2.

Table 2. Key RMS performance: responsiveness

(Adapted from Kritchanchai and Maccarthy, 1998)

Performance	Internal effects	External effects
1. *Cost*	High total productivity	Low price
2. Quality	Error-free process	On-specification product
3. *Responsiveness* • **Speed/Time** • **Dependability** • **Flexibility**	Ability to respond • fast throughput • reliable operation • ability to change	Desired result • a short delivery lead time • dependable delivery • frequent new product service, wide product range, volume and delivery adjustment

The present study goes beyond such literature, by developing ten manufacturing performance dimensions from the five previous competitive priorities. Performance on costs may be estimated through the unit cost of manufacturing. Quality performance is based on conformance to standards and it may be assessed by evaluating the percentage of scrap or rework. For time performance, three different dimensions are considered: speed of new product introduction, lead time, and cycle time. The dimensions of dependability performance are two: on time new product (NP) launch and on time delivery. The indicators of flexibility are three: flexibility to change product mix, flexibility to change volume, and the time horizon adopted to freeze planning (this last one on the basis that a shorter time offers more flexibility). For more details see Figure 1.

4.2. RMS and lean: manufacturing programs and performance

The practices are selected and measured according to the specification provided below. While there are many practices and programs in manufacturing management (Skinner 1969), the next four reasons are followed to choose the specific practices and programs for examination (Figure 2): 1) RMS definition: it encircles lean; 2) Practices from HPM programs traditionally recognized as part of lean manufacturing (JIT, TPM, TQM, HRM); 3) Other

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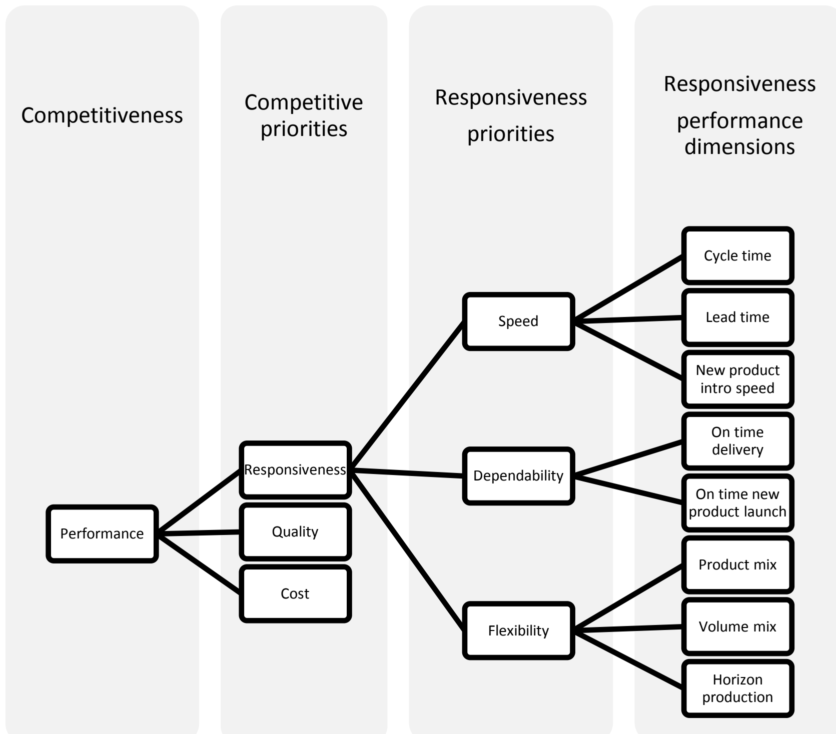
practices from other HPM programs related to lean; 4) Practices from HPM programs which have been theoretically or empirically associated with one or more specific dimensions of operational high performance.

Figure 1. RMS and manufacturing performance



Thus, drawing on the above, the following propositions on reconfigurability are presented:

Proposition 1. Lean related practices are linked to some HPM programs.

Proposition 2. There will be certain conditions of lean related HPM programs that might enhance reconfigurable related performance dimensions.

Proposition 3. Plants are searching for performance dimensions offered by RMS.

Figure 2. RMS: lean and HPM programs

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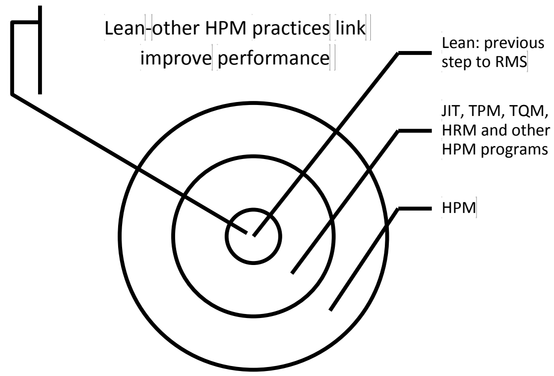

These propositions are based on the hypothesis that a RMS can be best implemented if it is carefully linked to current lean contexts. Hence, Propositions 1, 2 and 3 are critical if this paper is to develop a "theory of RMS implementation from lean and its linkages with HPM practices and programs". In addition, these propositions must be evaluated in the context of prior published literature within the domain of lean effectiveness. Towards this end, a systematic review of major journals yielded 31 lean related models that are relevant to this discussion. They are reviewed in the following section.

5. HPM practices, programs and performance

HPM project's literature is relatively recent. The first article appeared at the end of 1980s (Flynn et al., 1989). Since then, the project has given place to hundreds of publications and results (and counting) in professional journals. As matter of fact, few months ago one of the last ones related to lean (specifically JIT) was published in IJPE (Furlan et al., 2011). This body of literature is mainly focused on performance dimensions and manufacturing programs such as lean, TQM, JIT, MS, T, JIT and TPM and their practices (Schroeder and Flynn, 2001). A great characteristic of the international HPM project is that it is based on an outgoing well-defined and structured international database. There are research groups from dozens of universities from 14 countries which have contributed to collect data from thousands of plants worldwide. It is part of a reduced group of international investigations in OM, which originated more than 30 years ago. Therefore, it is a well consolidated and quite sophisticated international research.

Besides, the research for reconfigurable manufacturing goes as far as 1990 with Liles and Huff. Furthermore, the idea of agile manufacturing started in 1991 by Iacocca Institute, enabling short changeover times between manufacturing different products (Sanchez y Nagi, 2001). Ever since then, one of the agile production system trends in flexibility has been towards reconfigurability (e.g. Sheridan, 1993). On the other hand, as far as responsive performance dimensions goes, it is not limited only by the search of reconfigurability (Bozart and Chapman, 1996), and it has been a challenge since as early as 1988 (e.g. Stalk and Hout, 1990).

To answer the research questions in section 1, the studies were selected with the following characteristics:

- Method for data collection
  - Questionnaire, as a basis for the comparison of studies with the same methodology.
  - Studies with case studies.

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  - Theoretical studies
- Phenomena of interest: lean, HPM programs and manufacturing performance.
- Observation Unit: plants, industrial companies and their managers and workers.
- Sector: manufacturing industries.

In total, more than 60 papers from prominent journal (e.g. JOM, IJOPM, POM, etc.) for quantitative synthesis of lean, HPM programs and performance were identified. Hence some HPM programs are briefly reviewed to globally examine present context conditions and linkage set in stage for reconfigurability. An approximation of RMS in the HPM stage is made. The starting point is the conceptualization of RMS, where Mehrabi et al. (2000) define it along the same line of systems such as lean.

TQM, JIT, T, MS, HRM, and TPM were chosen for the following two reasons: 1) Selection of inter-related practices to combine into practice bundles associated with those six HPM programs. Individual practices are used to investigate the association between multidimensional performance and practice linkages, since this paper is interested in the interconnection among manufacturing practices in order to get high performance; and 2) They consist of a comprehensive set of practices involving not only social but also technical aspects of manufacturing and emphasize continuous improvement (Schonberger, 1986). The six bundles are used to examine the relationship between practice linkages and operational performance because this paper is also interested in evaluating the synergistic effects of implementation of all complementary facets of lean in order to compare it to RMS.

Much of the literature reveals a number of HPM practices that are commonly associated with lean manufacturing. Summaries of some of the commonly practices from the literature, according to the corresponding HPM program, are provided in Tables 3 and 4. Since these programs represent broad concepts and there is no consensus on a single definition for them, a literature review was used to classify the techniques and practices of these programs and initiatives. The selection of practices and programs shown in the next two tables is not exhaustive nor is it the only appropriate one. Additionally, these practices are not unique to the specific HPM programs, but are illustrative for the purposes of presenting the theoretical arguments. From the literature review, both tables show practices from programs common to both lean manufacturing and HPM: Table 3 has data from HPM project studies and Table 4 from other studies.

As far as the six core HPM programs considered here, POM literature agrees that manufacturing strategy (MS), just-in-time (JIT), total productive maintenance (TPM), technology (T), total quality management (TQM), and human resource management (HRM) are conceptually and empirically well established (e.g. Furlan et al., 2011; Schroeder and Flynn, 2001; Cua, 2000; Flynn et al., 1994, 1995; McKone and Weiss, 1999; McKone et al., 1999; Sakakibara et al., 1997). All six are accepted as HPM programs (Schonberger, 1986, 1996; Schroeder and Flynn, 2001). Besides, successful Implementation of these programs is found to improve manufacturing performance and help companies gain a competitive edge.

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Table 3. HPM and lean practices: HPM literature

Authors	Year	HPM programs	Manufacturing practices	Basic premise and/or findings
Sakakibara et al.	1993	JIT	Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction.	From the HPM database, a Framework and Measurement Instrument for Just-In-Time Manufacturing is tested.
Flynn et al.	1994	JIT, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Setup time reduction. TQM: Top Management Quality Leadership, HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Using the HPM database, this paper finds a relationship between TQM, JIT and HRM practices in a disaggregated way.
Flynn et al.	1995	JIT, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system. TQM: Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement.	Using the HPM data base it shows relationships between practices from JIT and TQM (as infrastructure practices except for process control)
Filippini et al.	1996	JIT, TQM, HRM, T	JIT: Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TQM: Product design, Process Control, Feedback, Supplier Quality Involvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. T: Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	Using the HPM database, it empirically shows improvement initiative paths in operations, which includes JIT, TQM, HRM and T practices.
Forza	1996	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	It then identifies the work organization practices that are associated with lean production in the literature and examines their supporting role in relation to lean production practices. The result of this analysis is inserted in a reference framework for the study of the association existing between work organization and lean production practices, and tested using the Italian database from the HPM empirical research from its 3 sectors (electronics, machinery and auto suppliers)
Sakakibara et al.	1997	JIT, TQM, HRM	JIT: JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TQM: Product design, Process Control, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Using the HPM data base it shows relationships between practices from JIT, TQM (as infrastructure practices) and HRM (as infrastructure practices)
Morita and Flynn	1997	JIT, TPM, TQM, HRM, MS	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. MS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing-business strategy linkage, Manufacturing strategy strength	Taking the HPM database, a linkage is established among management systems (JIT, TQM, HRM and MS), practices and behavior in successful manufacturing strategy. TPM practices are seen as part of production control system. Although it does not test hard technology practices such as FMS, there are some technology management practices found as part of the links.

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Flynn et al.	1997	JIT, TPM, TQM, HRM, T, MS	JIT: JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing. TPM: Predictive/ preventive maintenance. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. T: Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing MS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing-business strategy linkage, Manufacturing strategy strength	It sums up 3 studies from the HPM project. Taking 2 of them, Flynn et al. (1995) shows the impact of TQM and JIT practices on performance and competitive advantage, using infrastructure principles and programs and practices combinations, and Bates and Flynn (1995) shows manufacturing technology innovations with HPM programs and practices, some at the aggregated and at the disaggregated level. Both papers use the HPM database to prove such programs and practices are crucial in the way to HPM.
Maier	1997	HRM	Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	HPM data shows HRM-Technology (product, process and information)-Competitiveness links
Nakamura et al.	1998	JIT	JIT/continuous flow production, Kankan/Pull system, Setup time reduction.	From the HPM database, this paper finds evidence for the impact of JIT practices
Flynn et al.	1999	JIT, TPM, TQM, HRM,	JIT: JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing. TPM: Predictive/ preventive maintenance, New process equipment or technologies. TQM: Process Control, Customer focus, Feedback, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	There was strong support for the notion that the use of HPM practices, alone and in combination with new manufacturing practices (i.e. infrastructure), leads to the achievement of simultaneous competitive Advantages. It uses the HPM data base.
Milling et al.	2000	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Process Control, Feedback, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	From the HPM database, it was found a link among JIT, TPM, TQM and HRM practices.
Milling et al.	2001	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Process Control, Feedback, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	There is a relationship among JIT, TPM, TQM and HRM practices. The HPM database was the basis for this study,
Cua et al.	2001	JIT, TPM, TQM, HRM	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	This paper tests, using the HPM database, relationships between implementation of TQM, JIT, and TPM and manufacturing performance. It also takes into consideration HRM practices. Evidence was found both in a aggregated and disaggregated levels.
Matsui	2002	JIT, TQM, HRM, MS	JIT only as a super scale TQM: Process Control, Feedback, Top Management Quality Leadership, Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. MS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing-business strategy linkage, Manufacturing strategy strength.	It shows the contribution of TQM, HRM, MS and IT practices, and JIT program as a whole in an aggregated level to technology management. IT uses the HPM data base from Japan only.

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Sohel et al.	2003	JIT, TQM	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction. TQM: Process Control, Customer focus, Feedback, Supplier Quality Involvement.	Evidence was found on the role of infrastructure practices from TQM program in the effectiveness of JIT practices, with implications for plant competitiveness. HPM database was used here.
Cua et al.	2006	JIT, TPM, TQM, HRM	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction. TPM: Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Using the HPM database, this study find evidence of integrations among practices from HPM programs, both in a aggregated and disaggregated levels.
Furlan et al.	2011	JIT	Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction.	Paper uses the third round of HPM international research project data set to find that upstream and downstream JIT are complements. This finding suggests the importance of managing the interdependencies both in designing and implementing upstream and downstream JIT in order to maximize operational performance.

Table 4. HPM and lean practices: POM literature

Authors	Year	HPM programs	Manufacturing practices	Basic premise and/or findings
Dean and Snell	1996	T, MS	T: Flexible automation (CAD/CAM/CIM/ FMS/CNC) MS: Formal strategic planning, Manufacturing strategy strength	The Strategic Use of Integrated Manufacturing: An Empirical Examination
McLachlin	1997	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Taking 54 lean-related papers, the author finds support that some management initiatives (now related to TPM, TQM, HRM) are necessary for the implementation of just-in-time manufacturing practices. A case-based research methodology was used for theory testing at six Canadian plants from different sectors, each which claimed to be implementing just-in-time manufacturing.
Kilpatrick	1997	Technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	It is a thesis with a framework to analyze manufacturing systems and assess the impact of various practices on system performance. A literature review of Lean Manufacturing resulted in the discovery of significant gaps in two areas: (1) modeling the effects of implementing Lean Manufacturing using control theory principles, and (2) a design framework for building Cellular Manufacturing Systems and making the transition from traditional manufacturing to Lean Manufacturing.
Boyer et al.	1997	TQM, HRM, T	TQM: Feedback, Top Management Quality Leadership HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce. T: Flexible automation (CAD/CAM/CIM/ FMS/CNC)	This research examines whether investments in advanced manufacturing technologies (AMTs) such as flexible manufacturing systems (FMS), computer aided design (CAD), computer aided manufacturing (CAM), robotics, etc., are more likely to lead to improved performance if they are supported by improvements in the manufacturing infrastructure (TQM and HRM). It uses 202 manufacturing plants from industries with high investments in technology.
Sahin	2000	JIT, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	The author provides a better understanding of the lean concept aiming to help decision makers implement it. It lists key features for lean systems and its important elements for manufacturing success.

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Authors	**Year**	**HPM programs**	**Manufacturing practices**	**Basic premise and/or findings**
Yusuf & Adeleye	2002	TPM	TPM: Predictive/ preventive maintenance, Planning and scheduling strategies. TQM: Product design, Process Control, Feedback, Continuous improvement.	It is a comparative study of lean and agile manufacturing with a related survey of current practices from 109 UK plants from different sectors. It shows that plants need may get better performance from agile than lean.
Salzman	2002	Technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	A thesis that says that manufacturing system design cannot be considered a science with formal principles and equations. The methodology used here to expand the knowledge of manufacturing system design is two-fold and includes an in-depth manufacturing system redesign and an investigation into the current uses, limitations, and appropriateness of value stream mapping (VSM)
Shaha & Ward	2003	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership, Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Paper uses 16 lean-related studies to empirically validate (1748 US plants from different sectors) lean practices from HPM programs (traditionally related to lean) and finds their positive contributions to operational performance, even when contextual factors are present.
Borda	2003	JIT, TPM, HRM	JIT: JIT/continuous flow production TPM: Predictive/ preventive maintenance HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	It presents a theoretical framework of lean with some of its features.
O'Rourke	2005	MS	Manufacturing-business strategy linkage, Manufacturing strategy strength	Part of a thesis where Lean and Six Sigma are presented. It identified several factors that appeared to significantly contribute to implementation success: Fusing business strategy with continuous improvement strategy, Leadership commitment and involvement in the deployment and implementation processes, The use of consultants that are proficient and experienced, A defined organizational model that links the continuous improvement efforts with the performance measurement system and senior leadership, Defined and standardized personnel selection criteria
Berg & Ohlsson	2005	MS	Communication of manufacturing strategy, Formal strategic planning	The purpose of this thesis was to develop a strategy for the implementation of lean production in the Wacol factory's manufacturing area.
Koenigsaecker	2006	MS	Manufacturing-business strategy linkage, Manufacturing strategy strength, Formal strategic planning	The first in a series of six articles complied in a book on lean tools examines the relationship between strategy deployment and lean manufacturing.
Deluzio & Hawkey	2006	MS	Formal strategic planning	Strategy has gained considerable attention as a process designed to more closely align breakthrough performance improvements with the organizational resources required for their success

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As of lean production system, many researchers argue that it is an integrated manufacturing system requiring implementation of a diverse set of manufacturing practices (e.g. Shah and Ward, 2003) which are part of different HPM programs. Further, they also suggest that concurrent application of these various practices should result in higher operational performance because the practices, although diverse, are complementary and inter-related to each other. Thus, agreeing with the linkage HPM foundation that simultaneous application of multiple practices has a significant positive impact on operational performance.

Therefore, this research finds significant support for proposition 1, since lean uses some of practices from all six HPM programs, as verified from studies both from the HPM project and the POM literature in general (Tables 2 and 3 above).

6. Lean contingency and practices linkages within HPM programs

This study seeks to examine some relationships of manufacturing programs that are currently implemented in plants worldwide. As said in the previous section, it examines and considers sets of practices that belong to six HPM core programs and their impact on performance. These practices are also part or have connections with lean manufacturing.

6.1. HPM/lean practices

The next Table (5) summarizes a review of HPM practices and their relationships to performance, by cross-listing key practices identified both with lean and JIT, TPM, HRM, TQM programs. This is based on most common perspective in the literature (lean view), which is the overlapping of lean with these four programs and impacting cost, quality, speed (cycle and lead time) (Figure 3). However, in Table 5 there is empirical evidence of not only these four programs having practices compatible with lean and impacting those 4 performance dimensions, but also impacting other dimensions (Furlan et al., 2011; Cua et al., 2006; Mckone et al., 1999; Flynn et al., 1995).

Table 5 takes the framework from Figure 3, by using the HPM literature from the most common lean practices and their positive impact on performance. As it can be seen in the table, all four common programs related to lean impact on the four performance dimensions: quality, cost, cycle time and lead time (from a higher order, the competitive priorities are quality, cost, and some elements of speed).

Figure 3. Common lean and HPM practices: lean view performance

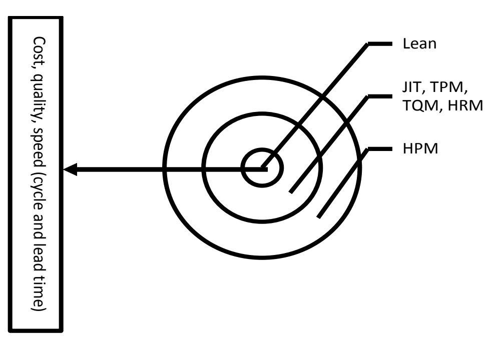

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Table 5. Lean and HPM practices (HPM view)

Authors	Year	HPM programs	Manufacturing practices	HPM data base	Relationship to performance
Flynn	1994	JIT, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Setup time reduction. TQM: Product design, Feedback, Top Management Quality Leadership. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	The authors show that, JIT, TQM and HRM practices improve Speed NP introduction.
Filippini et al.	1996	JIT, TQM, HRM	JIT: Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TQM: Product design, Process Control, Feedback, Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement.	Yes	Authors show evidence of JIT, TQM and HRM practices combined to improve on time delivery
Morita & Flynn	1997	JIT, TPM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies.	Yes	It shows that when combined with practices from other programs, JIT and TPM practices improve Speed NP introduction and On time delivery when Combined with practices from other programs, and Product mix and Volume mix when integrated with many programs
Sakakibara et al.	1997	JIT	JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction.	Yes	JIT practices improve volume mix.
Boyer et al.	1997	TQM, HRM	TQM: Feedback, Top Management HRM: Self-directed work teams/Employee involvement	No	When combined with practices from other programs, TQM and HRM practices improve the mix (volume & product)
Maier	1997	HRM	HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	Combined with technology, Self-directed work teams improve On time delivery, Product mix, Volume mix, and combined with technology, cross-functional workforce not only those but also horizon production schedule.
Nakamura et al.	1998	JIT	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction.	Yes	It shows JIT practices improving on time delivery
Milling et al.	1998	TPM	Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies.	Yes	TPM practices improve on time delivery
Flynn et al.	1999	JIT, TPM, TQM, HRM	JIT: JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing. TPM: Predictive/ preventive maintenance, New process equipment or technologies. TQM: Process Control, Customer focus, Feedback, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	Authors show JIT, TPM, TQM, HRM practices improve On time delivery, Product mix, Volume mix, when combined with practices from other programs
Milling et al.	2000	JIT, TPM, TQM, HRM	JIT: Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance, New process equipment or technologies. TQM: Process Control, Feedback, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	It confirms that JIT, TPM, TQM and HRM practices improve on time delivery.

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Authors	Year	HPM programs	Manufacturing practices	HPM data base	Relationship to performance
Cua et al.	2001	JIT, TPM, TQM, HRM	JIT: JIT/continuous flow production TPM: Predictive/ preventive maintenance, Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	JIT/continuous flow production improves volume mix. For TPM, Predictive/preventive maintenance, Planning and scheduling strategies improve on time delivery, New process equipment/technologies also volume mix. For TQM, Product design, Process Control and Feedback improve on time delivery, while Customer focus and Top Management Quality Leadership also volume mix. Finally HRM practices improve on time delivery. They all act better when integrated with other programs.
McKone et al.	2001	TPM	New process equipment or technologies	Yes	New process equipment or technologies improve on time delivery
Matsui	2002	JIT, TQM, HRM	JIT as a program TQM: Process Control, Customer focus, Feedback, Top Management Quality Leadership, Supplier Quality Involvement, Continuous improvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	TQM and HRM practices and JIT program improve this paper show some JIT and TPM practices to improve Speed NP intro, On time NPL, On time delivery, Product mix, Volume mix, when integrated with many programs
Milling et al.	2003	JIT, HRM	JIT: Lot size, Cellular/layout manufacturing, Setup time reduction. HRM: Flexible or cross-functional workforce.	Yes	The paper show evidence that these JIT and HRM practices influence all three dimensions of flexibility (product and volume mix and horizon production schedule
Sohel et al.	2003	JIT, TQM	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction. TQM: Process Control, Customer focus, Feedback, Supplier Quality Involvement.	Yes	Paper shows evidence that JIT and TQM practices impact on time delivery and product mix, both programs by itself and with other program(s).
Tu et al.	2004	JIT, TPM	JIT: Cellular/layout manufacturing, Setup time reduction. TPM: Predictive/ preventive maintenance.	No	Based on 303 US firms data from different sectors, this paper show some JIT and TPM practices to improve Speed NP intro, On time NPL, On time delivery, Product mix, Volume mix, Horizon production schedule
Cua et al.	2006	JIT, TPM, TQM, HRM	JIT: JIT/continuous flow production, Kankan/Pull system, Setup time reduction. TPM: Planning and scheduling strategies, New process equipment or technologies. TQM: Product design, Process Control, Customer focus, Feedback, Top Management Quality Leadership, Supplier Quality Involvement. HRM: Self-directed work teams/Employee involvement, Flexible or cross-functional workforce.	Yes	It shows that, JIT, TPM, TQM, HRM practices improve on time delivery and volume mix. But program practices act better yet when integrated with the other programs.
Furlan et al.	2011	JIT	Lot size, JIT/continuous flow production, Kankan/Pull system, Cellular/layout manufacturing, Setup time reduction.	Yes	Paper shows JIT practices improve cost, quality, on time delivery, volume mix

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The practices shown in Table 5 emerge from a fairly extensive literature review from 31 studies from several authors and provide a representative view of most components comprising lean manufacturing. The discussion and measurement of lean are necessarily related to the manufacturing practices that are commonly observed in the literature describing HPM from lean manufacturers. This gives strong support to proposition 1 and some support to proposition 2.

6.2. Beyond traditional lean literature: RMS-related performance

Data in Table 6 goes beyond the most common view, by showing that plants are searching for responsiveness (main competitive priority offered by RMS), giving support to proposition 3. Hence, Table 6 summarizes the responsiveness data in Table 5, by presenting the broader view of lean manufacturing from a HPM perspective, where the studies analyzed show that the same practices from the HPM programs in Figure 3 may not only get high performance in quality, cost, cycle time and lead time but also in the following dimensions: speed new product introduction, on time new product launch (NPL), on time delivery, product mix, volume mix, and horizon production schedule (in dimensional terms it means an element of speed, three elements of dependability, and three elements flexibility, respectively). As it can be seen, there are some variances in how the selected practices impact these dimensions.

Table 6. Broader view of lean and HPM programs: responsiveness

HPM program	Performance		
	Dimension	Responsiveness priority	Priority
JIT, TPM, TQM, HRM	Speed NP intro	Speed	Responsiveness
JIT, TPM both partial[1]	On time NPL	Dependability	
JIT, TPM, TQM, HRM	On time delivery		
JIT, TPM, TQM partial, HRM	Product mix	Flexibility	
JIT, TPM, TQM, HRM	Volume mix		
JIT, TPM both partial	Horizon production		

All these practices may lead to high performance in new product introduction speed, on time delivery, product mix and volume mix. Only the practices, lot size, cellular/layout manufacturing and setup time reduction (all from JIT) and predictive/preventive maintenance (TPM), may produce higher performance horizon production schedule. And these same practices but lot size are the only ones here that show improvements in time new product launch. All JIT practices but product design and all HRM practices may result in better cycle times.

6.3. Beyond traditional lean literature: technology and manufacturing strategy

Following the HPM broader view on lean manufacturing, Table 7 extend beyond the most common perspective of JIT, TQ, TPM and HR programs. It includes practices from technology (flexible automation and group technology are both particularly important not only because of present flexible automation, but because future RMS may be enclosed here) and manufacturing strategy programs, which both support getting high performance in multiple dimension: cost, quality, speed (cycle time, new product introduction speed and lead time), dependability (on time

[1] Partial means that not all practices of the particular program have an effect on performance.

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delivery), and (flexibility product mix, volume mix and horizon production). All practices may produce higher performance in all scales but in cycle time, new product introduction speed, lead time and horizon production. All practices but flexible automation may be the ones in this table to get better performance in cycle time and NP introduction speed. Better lead time may be obtained here from all technology related practices and also from formal strategic planning and manufacturing strategy strength. For its part, flexible automation (CAD/CAM/CIM/ FMS/CNC) and group technology-cellular manufacturing for T, and formal strategic planning for MS may be the only practices here to lead to higher performance in horizon production.

Table 7. Technology and manufacturing strategy practices in lean: HPM view

Authors	Year	HPM program	Manufacturing practices	HPM data base project	Relationship to performance
Flynn	1994	MS	Communication of manufacturing strategy	Yes	This practice improves Speed NP introduction
Filippini et al.	1996	T	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	Yes	When combined with other practices, technology practices improve Cost , Quality, Lead time, On time delivery
Dean and Snell	1996	MS and T	T: Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing. MS: Communication of manufacturing strategy, Formal strategic planning, Manufacturing strategy strength	No	T and MS practices improve Quality, Lead time, On time delivery, when combined with practices from other programs
Boyer et al.	1997	T	T: Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing.	No	When combined with practices from other programs such T practice leads to better performance on Product and Volume mix .
Cua et al.	2001	MS	Formal strategic planning	Yes	Practice improves quality and on time delivery (even better when integrated with other programs)
Matsui	2002	MS	Communication of manufacturing strategy, Formal strategic planning, Manufacturing-business strategy linkage, Manufacturing strategy strength	Yes	Communication of manufacturing strategy combined with its program improves Cost , Quality, Cycle time, Lead time, On time delivery, Product mix, while the rest three MS practices improve not only those 6 performance dimensions but also Speed NP introduction.
Milling et al.	2003	T	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	Yes	Both T practices improve all three flexibility dimensions (product and volume mix and horizon production schedule
Cua et al.	2006	MS	Formal strategic planning	Yes	Practice improves cost, quality, on time delivery and volume mix (even better when integrated with other programs)
Ahmad et al.	2010	T	Group technology-cellular manufacturing	Yes	This paper confirms correlation between modularization and both cycle time and NP introduction speed, but to be effective it needs functional coordination
Danese and Filippini,	2010	T	Group technology-cellular manufacturing	Yes	It shows a correlation between modularization and both cycle time and NP introduction speed

Table 8 sums up performance dimensions improved by T and MS. This presents a broader view of lean manufacturing from a HPM perspective, where the studies analyzed show that practices from MS and T HPM programs, which may help getting high performance in quality, cost, cycle time and lead time, speed new product introduction, on time delivery, product mix, volume mix, and horizon production schedule (in dimensional terms it means three elements of speed, one element of dependability, and three elements flexibility, respectively). This gives significant support to propositions 1, 2 and 3.

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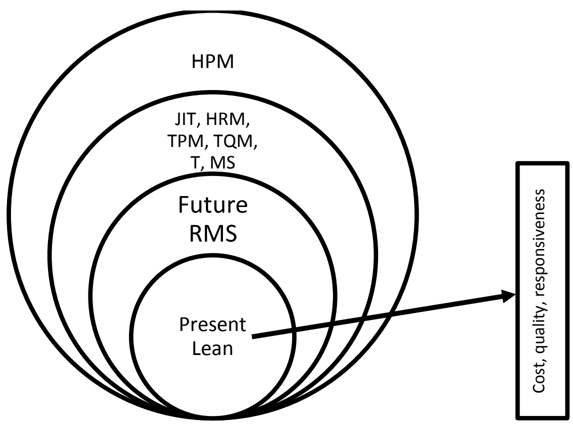
6.4. Insights from the HPM lean models

Taking the different studies from tables 3 to 8, Figure 4 proposes a general model for RMS implementation and operations. The model, founded on current HPM context, interconnects some key performance dimensions related to RMS (including the key priority responsiveness) to those practices and programs. The HPM groundwork about contingency and linkage is put as an emphasis to overview current manufacturing environments and practices where RMS may fit.

Table 8. HPM Technology and manufacturing strategy programs in lean

HPM programs	**Performance**		
	Dimension	**Cost, quality and responsiveness priorities**	**Priority**
T,MS partial	Cost	Cost	**Cost**
T,MS partial	Quality	Quality	**Quality**
T partial, MS	Cycle time	Speed	**Responsiveness**
T, MS both partial	Speed NP introduction		
T,MS partial	Lead time		
T,MS partial	On time delivery	Dependability	
T	Product mix	Flexibility	
T	Volume mix		
T,MS partial	Horizon production		

Figure 4. General model for RMS implementation: HPM context and performance



7. Conclusions

This paper reviewed systematically more than 31 studies, where current characteristics of lean were reviewed and some its practices classified according to HPM, some key performance dimensions related to RMS were also described. HPM taxonomy of lean was provided to illustrate overlapping in relation to RMS. The foundation of HPM linkage was put as an emphasis to overview current manufacturing practices where RMS may fit. Thus, this study takes some of the performance dimensions that RMS promises to improve, which at present are being sought after by LM practices in combination with other HPM manufacturing practices. In general, there seems to be empirical evidence of the relationship between the manufacturing practice bundles and performance dimensions used here.

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However, cautions should be taken about making general conclusions of not getting any of the performance dimensions since the relationships among practices are difficult to determine empirically. The analysis shows that RMS may not a complete solution for manufacturing plants to meet all performance dimensions, so it is promising to take advantages of other practices in a RMS implementation: linkages are extremely important for RMS to meet its expectation. The finding that each of the bundles contributes to performance may seem intuitive, but in the past such a result has not been reported unanimously in the literature. For instance, Flynn et al. (1995) report that JIT and common infrastructural practices have a positive effect on performance but that TQM has no significant effect. On the other hand, Sakakibara et al. (1997) show JIT by itself has no significant effect on performance. Also, McKone et al. (2001) find that JIT, TQM and TPM all contribute to their weighted performance index. However, Cua et al. (2001) illustrate different results in TQM, JIT and TPM when their practices are disaggregated. For the different practice combinations to get high performance see Table.

In lean contexts, the implication for managers of plants implementing RMS is a performance advantage compared to plants that don´t. These findings provide unambiguous evidence that the synergistic effects of all bundle practices are associated with better manufacturing performance. Therefore, HPM practices or programs, used to meet some performance dimensions of a manufacturing system, have been generalized. These practices can be used to compare and distinguish lean manufacturing, as well as a starting point for future implantation of RMS in the search for HPM. The study findings show several bundle configurations from HPM practices and programs (aggregated or disaggregated) to get high performance, endorsing the importance of taking into account the contingency and practice linkage paradigms before selecting and implementing RMS.

To sum it all up, RMS seems to be one of the most effective initiatives to help improving some key performance dimensions such as cost and responsiveness in some contexts, but there are two important issues to consider when implanting it in the right context: 1) it must be linked to other practices in a plant to be in the right path to HPM; and 2) it is not the complete solution to meet all, or even most, of manufacturing performance dimensions, to simply substitute current manufacturing practices and systems.

In practical terms, it may well be said that there may be many RMS prototype systems already developed, most of them machine-level systems, but the specialized literature does not show any specific attempt made to operatively link an RMS to other manufacturing practices.

Finally, the resulting analytical framework is proposed as future empirical research. Specifically, this paper identifies some directions to go from here on:

1. An important issue is how to help plants evolve from a non-configurable system to a reconfigurable system. It is worth to note that performance dimensions which will be delivered by reconfigurable systems are already being targeted by manipulating a set of non-reconfigurable practices at the organizational and technological level. They can be improved and extended with the consideration of time and changes.

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2. Since RMS may not be a "one size fits all", a potential approach to implement an RMS in a plant is contingent to the context needs.
3. RMS concept is not a complete solution for manufacturing plants to meet all performance dimensions, so it is promising to take advantages of other practices in a RMS implementation. Likewise, linkages are extremely important for an RMS to meet its expectation. For example, in order to avoid trade-off among the two dimensions shown here with more room to improve (cost and flexibility), plants have to consider the practice linkage leverage among existing programs such as JIT, HR, TPM, etc.

Acknowledgments

This research has been partly funded by the Spanish Ministry of Science and Innovation DPI-2009-11148, and by the Junta de Andalucía project P08-SEJ-03841). The authors wish to acknowledge the Spanish and Andalucian Governments for their support.

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