Meta-analysis of Performance: Summarizing Research for Implementation of Reconfigurability

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***Abstract*—**The aim of this study is to identify the conditions of implementation for reconfigurability in summarizing past flexible manufacturing systems (FMS) research by drawing overall conclusions from many separate High Performance Manufacturing (HPM) studies. Meta-analysis will be applied to links between HPM programs and their practices related to FMS and manufacturing performance with particular reference to responsiveness performance. More specifically, an application of meta-analysis will be made with reference to two of the main steps towards the development of an empirically-tested theory: testing the adequacy of the measurement of variables and testing the linkages between the variables.

***Keywords*—**FMS (flexible manufacturing system), HPM (high performance manufacturing), reconfigurability, RMS (reconfigurable manufacturing system), responsiveness

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I. Introduction

OPERATIONS MANAGEMENT (OM) literature has somehow established that increasing global competition has made the industry turn its attention to critical issues such as competitiveness, productivity, quality, etc. Hence, manufacturers seek new approaches to manufacturing processes, and explore new boundaries of technology. Therefore, plants are looking for ways to respond quickly to changes induced by new regulations and market. As a result, flexibility has become an important tool in this struggle for success, i.e. ability to meet an increasing variety of customer expectations without excessive costs, time, or organizational disruptions, by increasing the range of products available, improving a firm's ability to respond quickly, and achieving good performance over a wide range of products. From this perspective, one of the frequently prescribed remedies for the problem of decreased productivity and declining quality is the automation of factories. More specifically, technologies such as Computer Integrated Manufacturing Systems (CIM's), robotics and Flexible Manufacturing Systems (FMSs) have been the focal points of much research and exploration.

Besides, the attempt to increase competitiveness, through the search and exploration of the best solutions in order to accomplish better manufacturing operations, seems never ending. Altogether, many times these solutions create new practices or initiatives in operations as general tendencies within manufacturing plants.

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This permanent research, to get better and better manufacturing performances, continues, and promises to continue drawing multitude of professionals, managers and academics worldwide, not only from OM, but also from the whole community of business administration, economics and engineering in general.

Thus, global trends by manufacturing plants are to employ increasingly flexible manufacturing practices. This trend is driven by the hypothesis that their utilization will result in improvements in some measures of performance such as higher responsiveness. Unfortunately, FMS investments do not yield the desired results as explained next.

Empirical studies show, on the one hand, that FMS is not living up to its full potential, and, on the other, that even some manufacturers many have purchased FMS with excess capacity and features. Besides, there are a variety of problems associated with FMS such as training, reconfigurability, reliability and maintenance, software and communications, and initial cost [1]. Paradoxically, the main disadvantage with FMS is its inflexibility. Its quality is often called "short-term" flexibility in the literature. The ability to change the system to produce new products is "long-term" flexibility.

This paper takes on the "reconfigurability" problem of FMS. Reconfigurability provides exactly the functionality and capacity needed, 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. A Reconfigurable Manufacturing System (RMS) is simply one way that manufacturers may achieve reconfigurability.

There are no proposed and tested RMS models in OM, since it is at the final prototype stage of ***User Experience*** [2]. On the other hand, many researchers have proposed and tested FMS models, but all of them are isolated representations rather than cumulative studies that systematically build upon each other for reconfigurability deployment. This meta-analytic review of FMS research is simply a first, but necessary step in the process of developing a theory for the near future RMS deployment.

From some of existing manufacturing programs, this paper explores stage set in for reconfigurability from the High Performance Manufacturing (HPM) literature (i.e. it is an integrated set of processes designed to achieve a sustainable global competitive advantage through the continuous improvement of manufacturing capability) to globally examine present non-reconfigurable conditions of practice linkages [3], [4]. The starting point for this is the conceptualization itself of

RMS that revolutionizes or at least evolves from FMS, improving multidimensional performance [5], and, thus, RMS is studied as part of HPM. Thus, this paper reviews several studies that have been presented in major operations management and other cross-disciplinary journals. Cumulatively they represent the current viewpoints in the academic arena on FMS's role within the plants, as a previous step to RMS.

Hence, a general framework for understanding the future role of RMS is presented. It takes into account the fact that present FMS interrelates to many of the HPM programs such as just in time (JIT), total quality management (TQM), human resources (HR), manufacturing strategy (MS) and technology (T).

Based on the above, the following research questions are presented: are there manufacturing competitive performance dimensions offered by reconfigurability being currently sought by current non- reconfigurable plants? Are there other technology practices linked to FMS? Are there HPM programs linked to FMS? Are there non-reconfigurable technology practices related to reconfigurable performance dimensions? To answer them, the paper's objectives will then be to review several studies individually, to present the pertinent parameters of the research, to review existing research across these parameters in order to evaluate its comprehensiveness as a whole, to explore gained insights by relating performance dimensions and manufacturing practices that motivate need for further work, and to present models for further research.

II. Literature Review

Plant management should be very familiar with being recommended to adopt each and every manufacturing initiative appearing as a trend such as lean, manufacturing strategy, etc. This work, on the contrary, marks away from such idea, by associating to the company the concept whose focus is linking only the manufacturing system (with or without adaptations) which jointly achieves a competitive organization. But before such linkage between practices, there must be a strategic plan of contingency based in the particular context of the company, in order to select, adapt (when needed) and implement 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 with a deliberated path of continuous improvement. This approach, called High Performance Manufacturing (HPM) [3], will subsequently be used to study current non-reconfigurable conditions set in stage for future RMS implementation.

Thus, the increment of world competition and the assessment that management approaches transcend national frontiers have created the movement of the international data base project 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. The stage of FMS: future RMS implementation

The search to develop the technology for Reconfigurable Manufacturing System (RMS) started in the mid-nineties as a cost-effective response to market demands for responsiveness and customization. According to [5], 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 colleagues assess that for a manufacturing system to be readily reconfigurable, it must possess certain key characteristics which includes: 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.

However, 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. On the one hand, high performers (i.e. world class manufacturers) have been in the advance party of the "best practices" in OM. 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, the concept behind HPM is not establishing the trend of a new practice or program, but focusing manufacturing in order to get global high performance.

Organizations, which permanently adopt HPM philosophy, look for opportunities to improve in multiple competitive priorities, such as quality, cost, delivery, flexibility, innovation, etc. Such improvements are essential in the company for its survival, benefit, and [3].

Hence, there are still other key issues to consider when implementing a new manufacturing program. For instance, [39] assesses that a new manufacturing program such as lean manufacturing, TQM, TPM, etc., is introduced every five to ten years as the panacea for getting high performance; and 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, Cua and his coauthors have proposed to also consider the linkage of manufacturing programs by implementing practices common to all existing programs and linking new programs with currently practices.

Therefore, 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.

Besides, using the HPM concept above, one may say that even if all industries were to experience ever-changing environments, it is very unlikely that all plants be forced (especially 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 to just abandon many of their manufacturing programs in order to adopt RMS. For instance, if taking FMS (one of these current programs and considered the previous step for RMS), it has been studied in HPM as part of flexible automation (FA) (Fig. 1).

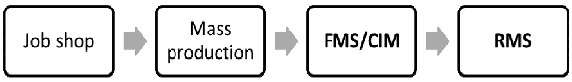

Fig. 1 FMS as previous step to RMS

FA, for its part, is an attempt to combine advantages of fixed automation with those of programmed automation. Using this method, plants are able to obtain simultaneously low costs per unit and a high degree of flexibility. FA is then defined as an advanced integrated system of hardware and software that makes it possible to design and produce automatically a predefined variety of products. There are various types of FA, besides FMS, such as automated transport and warehousing, production cells and numerical production, computer numerically controlled (CNC)/direct numerically controlled (DNC) production, etc. Due to RMS' technological characteristics, it is considered the next step to FMS, and as such, it must be framed within FA as well.

Thus, from the point of view of technology (FMS), this paper considers RMS best fit as part of FA, which has components from all three areas of technology:

1. *Process/manufacturing technology* may be defined as the equipment and the processes for making products (e.g. Maier, 1997).
2. *Product technology* is defined as the equipment and processes to design and build new products.
3. *Information technology* is concerned with the processes and equipment for information treatment.

In addition, the effectiveness of all HPM programs is closely interrelated with technology, and, bidirectionally, this interrelation influences the success of any technological system in a plant: technology and other HPM practices together affect performance. A possible missing link between technology and other areas of a plant is an important cause of failure.

Furthermore, what a plant does (and even what a plant does not do) will reflect on its outcome. Therefore, the decision to use certain technology practices, or others, or none altogether (no action taken) always has an impact on performance. This makes room for some differences that may distinguish high from standard performers. For instance, considering different technologies in use, high performers are more innovative and are more likely to introduce innovations such as CAD, CNC/DNC, FMS, or soon RMS than standard performers.

In conclusion, even after RMS is fully available and operational (delivering all promised features) there is still the fundamental matter of whether RMS will be a "best practice" for all plants in all industries. The contingency argument, from HPM, has something to say about this matter: 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 industries in general to face manufacturing responsiveness (i.e. the main characteristic offered by RMS), it is important to know what high performers are doing now globally to meet requirements of responsiveness performance with available manufacturing practices and contexts.

III. Stage For RMS: An HPM Framework

So far, the paper has set a stage, which may relate some HPM practices, from present FMS, in order to analyze future RMS implementation and operations, using plant contingency, practice linkages and multidimensional performance. There are two main aspects of such framework in the present study: 1) the techniques and practices of HPM programs; and 2) the effect of these programs on performance. In this section, each component of the framework and the propositions are developed.

A. Competitive Performance

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. Furthermore, "cumulative capabilities" describes 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 [38].

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 situations, where plants need to perform well in a multidimensional level. However, most existing literature often ignores the role of manufacturing goals and uses a one-dimensional performance measure in the models and empirical tests. Reference [6] argues that in order to do justice to the contingency argument both the multidimensionality of performance and the strategic goals must be incorporated into the analysis. Their position is that three components must be explicitly measured: (1) goals; (2) practices; and (3) multidimensional performance.

Following the above, in order to examine the relationship between initiatives and performance, this study focuses not only on the two competitive priorities from manufacturing, cost and responsiveness, which literature, e.g. [5], 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 responsiveness is necessary to identify the drivers of high performance and sustainability of these competitive performances. Operations management researchers have contributed to the literature by examining the conditions under which specific practices, resources or structural arrangements are valuable.

Following 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 [7]. The last three priorities are being used as the integrated parts of responsiveness. These authors assess that responsiveness not only covers them but addresses how to utilize and manage these priorities 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 basic competitive priorities of manufacturing performance (cost, quality, delivery/dependability, time and flexibility) represent one of most common approaches for performance measures. The five priorities are briefly summarized in Table 1.

TABLE I
PERFORMANCE DIMENSIONS

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

The present study goes beyond such literature, by developing ten manufacturing competitive performance dimensions from the five previous competitive priorities (Fig1). 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 launch and on time delivery. The dimensions 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).

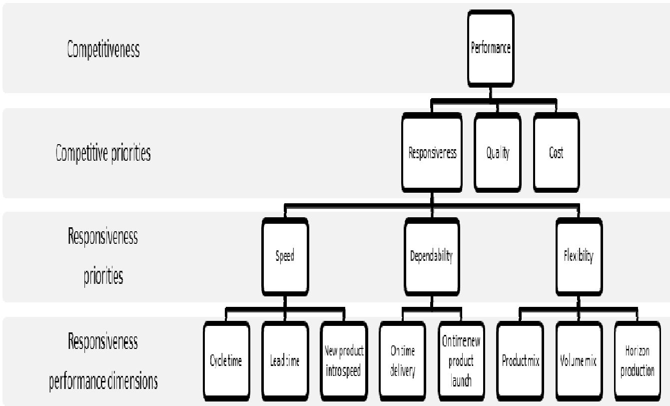

Fig. 1 Competitive performance

A. Manufacturing practices and performance

A good understanding of a plant may help identifying manufacturing practices which meet performance dimensions, providing basis for why and how practices have competitive value. In order to do so, this study builds on two key roles in establishing the theoretical argument for why practices matter [6]:

- The resource-based (routine-based) view of the firm (RBV). Based on the idea that the manufacturing practices (not the resources themselves) are subject to inimitability, causal ambiguity and are context-specific. Therefore, they offer value for the organization that makes use of them.
- The evolutionary theory. From the literature, they are supported on the proposal that the organizational processes (e.g. routines) are shaped over time and are subject to path dependency and inertia. So, at least in the short term, routines are difficult to imitate. The routines are also embedded in the organizational context, which makes their potential contingent value higher than in any other context.

Taking these two arguments into consideration, the practices are selected and measured according to the specification provided below.

While there are many practices and programs in manufacturing management, the next four reasons are followed to choose the specific practices and programs for examination (Fig. 2):

1. Programs and practices and recognized as HPM [3].
2. HPM programs with links to FMS.
3. Technology practices which have been theoretically or empirically associated with one or more specific dimensions of operational performance (included responsiveness dimensions offered by reconfigurability).

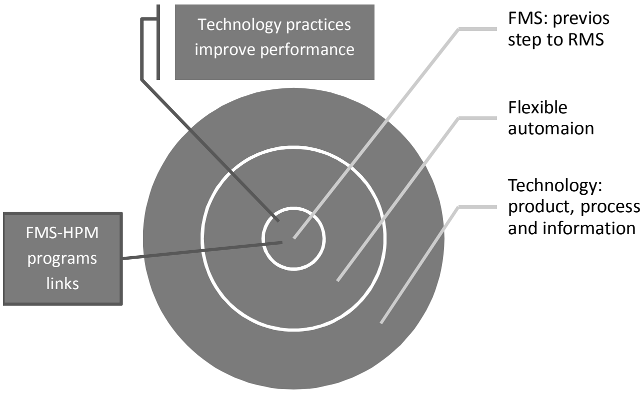

Fig. 2 HPM framework: stage for RMS

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

Proposition 1. FMS is linked to HPM programs.

Proposition 2. FMS is linked to other technology practices.

Proposition 3. There will be certain combinations of non-reconfigurable technology practices interconnected with FMS that might enhance dimensions of performance related to RMS.

Proposition 4. FMS by itself does not deliver all performance dimensions offered by RMS.

Proposition 5. Non-reconfigurable plants are searching for performance dimensions offered by RMS.

These propositions are based on the hypothesis that RMS can be best implemented if it is carefully linked to current contexts, especially FMS. Hence, all five propositions are critical if this paper is to develop a "theory of RMS implementation from FMS and its linkages with to HPM programs and practices". In addition, these propositions must be evaluated in the context of prior published literature within the domain of FMS effectiveness. Towards this end, a meta-analysis of major journals yielded 33 HPM models with programs related to FMS that are relevant to RMS' discussion. They are reviewed in the following three sections.

IV. Overview Of Linkages And Contingency

In order to properly meta-analyze, facilitating comparison of studies, the following was done:

- To define clear and homogeneously concepts from HPM programs, technology areas (product, process and information) and their practices, FMS as part of technology, and performance.
- To use mainly papers from the HPM international project.
- To complement with papers from sources other than the HPM project with the following requirements:
    - Scientific measures that were valid, reliable, shared.
    - Detailed information on sampling design and resulting samples.
    - Useful information for future comparisons: mean, standard deviation for each variable; correlation matrix, sample size, missing values, and treatments.
- To increase explicitness level with respect to assumptions, conditions, and hypotheses.

Thus, to answer all propositions from previous section, there was an overview of current FMS, manufacturing practices and programs, and performance dimensions, in order to be grouped according to HPM framework (Fig. 2). Hence, several prominent journals were reviewed for research on FMS-HPM programs and performance relationships, since 1984. The journals included more than 49 papers in operations management (Journal of Operations Management, Production and Operations Management, International Journal of Operations and Production Management, etc.). The goal was to provide a reasonable representation of the theoretical and empirical research on FMS for a potential RMS deployment.

Then, a categorization of the HPM groups (programs and performance) was made. The focus was to compare and contrast them with respect to several important issues, summarizing the scope of the groups' definitions and their empirical relationships. Besides, this paper takes the conceptualization of RMS, where [5] define it along the same line of FMS. Thus, since FMS is part of flexible automation [25] this part explained "manufacturing technology program" from which the flexible automation is part of. Thus, relationships between FMS and some HPM programs are also shown.

The first 27 models that focused on FMS deployment and its e1ectiveness around HPM programs provide a reasonable representation of the theoretical and empirical research on e1ective RMS deployment.

A review of the models revealed two distinct levels of analysis in the relationship to FMS represented in the next two Tables: 21 models from HPM programs interconnected to FMS, and 6 models from technology practices (other than FMS), where FMS is inserted. Table II illustrates the literature of linkages between flexible automation (i.e. which includes FMS) and the HPM programs JIT, TQM, HR, MS, and practices from technology (T) different from FMS. Thus, it provides a very general summary of the models of HPM programs with links to FMS, which are discussed below chronologically. The Table presents a framework of these models with proposed structures of HPM programs-FMS relationships within manufacturing plants, and whether or not a model is framed within the data base of the HPM international project.

TABLE II
Linkages Between FMS And HPM Programs

Authors	HPM programs	HPM project
[8]	JIT	Yes
[9]	JIT	Yes
[10]	JIT	Yes
[11]	JIT	No
[12]	JIT	Yes
[13]	JIT	No
[14]	JIT	Yes
[15]	JIT, TQM, HR, MS	No
[16]	JIT	Yes
[17]	HR, MS	No
[18]	HR, T	No
[19]	JIT, TQM, MS	No
[20]	JIT, TQM, HR, MS, T	Yes

Authors	**HPM programs**	**HPM project**
[21]	HR	No
[22]	T	No
[23]	TQM, HR	No
[24]	JIT, TQM. HR, MS, T	Yes
[25]	JIT, TQM, HR, T	Yes
[26]	TQM, T	Yes
[27]	TQM, HR	No
[28]	TQM	No

Technology: flexible automation (FMS, CNC, CAD, etc.)

As far as the HPM core programs being considered in Table II, OM literature agrees that manufacturing strategy (MS), just-in-time (JIT), manufacturing technology, total quality management (TQM), and human resource (HR) are conceptually, theoretically, and empirically well established. All five are recognized HPM programs. Successful Implementation of these programs is found to improve manufacturing performance and help companies gain a competitive edge.

Turning to FMS, already recognized in this paper as part of technology, the literature seen above asserts that for FMS to give competitive results must have linkages to JIT, TQM, HR, and manufacturing strategy. Thus, Table II shows significant support for proposition 1.

On the other hand, the selection of practices shown in Table III is not exhaustive nor is it the only appropriate one. Additionally, these dimensions may not be unique to the technology HPM program, but are representative for the purposes of presenting the theoretical arguments. From the literature review, the Table shows in chronological order models of practices, other than FMS (flexible automation and group technology), from the three areas of technology (process, product and information) briefly mentioned in section 2. These practices are interrelated with FMS, giving support to proposition 2.

TABLE III
CONTINGENCY: OTHER TECHNOLOGY PRACTICES

Authors	*Area of T*	*Manufacturing practices*	*HPM project*	*Basic premise and/or findings*
[20]	Product technology	Concurrent engineering/phase overlapping	Yes	Product technology. It was found as an intermediate (between hard and soft) technology practice
[29]	Product, process and information technology.	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment, IT	Yes	Product, information and process technology. All three influence plant competitiveness
[30]	Process technology	Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	Process technology. A key factor for plant success
[31]	Process technology	Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	Process technology. It was defined as a technology practice needed for competitiveness
[32]	Product and process technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	Product and process technology. They were found as a competitive technology practices
[33]	Product and process technology	Product design simplicity, Interfunctional design effort, Effective Process Implementation	Yes	Product and process technology. Evidence was shown both by themselves and combined with other practices

V. ANALYSIS: HPM TECHNOLOGY AND PERFORMANCE

A. Categorization of the models: specific linkages in FMS

The focus in the following discourse will be to compare and contrast models of technology practices, where FMS is inserted, with respect to performance. Table IV summarizes chronologically the scope of the model definitions and their empirical validity. As it has been shown, RMS is being compared mostly, and even considered the next step, to FMS, and since the latter is part of technology program, the Table presents eight practices within this program (from its three areas: information, product and process technology), which may lead to improvements in cost, quality, cycle time, new product introduction speed, lead time, on time delivery, fast delivery, product mix, volume mix, and horizon production schedule.

TABLE IV
PERFORMANCE AND TECHNOLOGY

Authors	Technology area	Manufacturing practices	HPM project	Performance relationship
[29]	Product, process and information technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment, information technology	Yes	Product and information technology positively affect lead time, on time delivery, product and volume mix and horizon production schedule, but only when combined with process technology. Process technology practices directly leads to better performance on the same 5 dimensions.
[30]	Process technology	Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	Process technology practices leads to better performance on cost by reduction of defects, quality (defect reduction), on time delivery and all three dimensions of flexibility.
[31]	Product and Process technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	Product technology practices combined improves quality (reduction of defects), cost (by reduction of defects), lead time, on time delivery, and all three dimensions of flexibility, but need to be fitted with process technology. Process technology practices directly improve same 7 performance dimensions.
[32]	Product and process technology	Product design simplicity, Concurrent engineering/phase overlapping, Interfunctional design effort, Willingness to Introduce New Technology, Anticipation of New Technologies, Effective Process Implementation, Proprietary equipment	Yes	When combined with process technology, product technology practices improve quality (reduction defects), cost (by reduction of defects), lead time, on time delivery, and all three dimensions of flexibility (product and volume mix and horizon production schedule). Process technology practices directly improve same 7 performance dimensions.
[34]	Information technology	Information technology	Yes	Information technology positively influences all 9 performance dimensions.
[33]	Product and process technology	Product design simplicity, Interfunctional design effort, Effective Process Implementation,	Yes	Product and process technology practices improve cost, quality cycle time, speed NP introduction, on time delivery, production and volume mix, but better yet when integrated with other programs

Although all practices will lead to better performance in cost, dependability (on time delivery), and flexibility (product mix, volume mix, and horizon production schedule), the use of each individual of these practices will not mean higher performance in the other referred dimensions. Better quality is more likely to be obtained by all practices but willingness to introduce new technology, anticipation of new technologies, and proprietary equipment. These same three practices, as well as concurrent engineering/phase overlapping, do not show to lead to fast new product introduction and cycle time. Finally, only concurrent engineering/phase overlapping, proprietary equipment, and IT have shown improvements in lead time. Hence, the combination of these eight practices from all three technology areas, which are interconnected with FMS, might enhance all performance dimensions but on time new product lunch from dependability (the other seven dimensions related to all three responsiveness priorities are present: speed, flexibility and dependability). Therefore, this gives support for proposition 3.

VI. RESEARCH COMPARISON TO THE HPM FRAMEWORK

A review of the last six models revealed three levels of analysis: individual by FMS practices, combined by FMS and other technology practices, and organizational by FMS within the HPM programs. Table V provides a general summary of the models, which are discussed below in chronological order. A brief synopsis related to performance of these models is presented, along with proposed structures of the three technology areas within the plant, and general findings regarding these relationships. Tables V–VI present a depiction of the causal relationships practices-performance. It should be noted that in some cases the model depictions represent interpretations of how the models were proposed or tested. They include two FMS practices, flexible automation and group technology, since both are particularly important, not only because of current flexible automation needing group technology, but because future RMS may be enclosed here, as well as they both support getting high performance in multiple dimensions: cost, quality, speed (cycle time, new product introduction speed and lead time), dependability (on time delivery), and (flexibility product mix, volume mix and horizon production).

Table V shows that both FMS practices together may produce higher performance in all scales but in cycle time, and new product (NP) introduction speed. Group technology may be the only to get better performance in cycle time and NP introduction speed. This means that FMS fall a bit shorter on improving speed, giving some support to proposition 4.

TABLE V
PERFORMANCE AND FMS

Authors	*Tech. area*	*Manufacturing practice*	*HPM project*	*Performance Relationship*
[19]	Product, process and information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC)	No	FMS practice implementation improves quality, lead time, and on time delivery when combined with practices from other HPM programs
[20]	Product, process and information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	Yes	Both FMS practices have a positive effect on cost, quality, lead time and on time delivery, but only when combined with other FMS practices
[23]	Product, process and information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC)	No	FMS practice improves both flexibility mix dimensions (product and volume mix), but combined with practices from other HPM programs
[35]	Product, process and information technology	Flexible automation (CAD/CAM/CIM/ FMS/CNC), Group technology-cellular manufacturing	Yes	Both FMS practices improve all flexibility dimensions (product and volume mix and horizon production schedule
[36]	Process and information technology	Group technology-cellular manufacturing	Yes	This paper confirms correlation between FMS modularization and both cycle time and NP introduction speed, but to be effective it needs functional coordination
[37]	Process and information technology	Group technology-cellular manufacturing	Yes	It shows a correlation between FMS modularization and both cycle time and NP introduction speed

Table VI sums up performance dimensions improved by FMS practices and other technology practices. This presents a broader view of FMS from a HPM perspective, where the studies analyzed show that practices from the technology HPM program 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 proposition 5, since plants seem to be searching for nine out of the ten proposed dimensions.

TABLE VI
PERFORMANCE, TECHNOLOGY AREAS AND FMS

FMS	**Technology**	**Performance**

area		Dimension	Responsiveness priority	Priority
Both	1, 2, 3	Cost	Cost	Cost
Both	1 partial, 2 , 3	**Quality**	**Quality**	Quality
One	1&2partial,3	*Cycle time*		
One	1&2partials, 3	*Speed NP intro*	*Speed*	
Both	2partial,3	*Lead time*		
Both	1,2,3	**On time delivery**	**Dependability**	Responsiveness
Both	1,2,3	Product mix		
Both	1,2,3	Volume mix	Flexibility	
Both	1,2,3	Horizon production		

1: process, 2: product, 3: information. Partial means that not all practices of the particular program positively impact on performance.

Finally, some linkages between FMS, flexible automation (FA) and some HPM programs are shown in the general model in Fig. 3, which comes from the literature in Tables II-VI. It is never too repetitive to say that FA is not a standalone initiative, but it is intrinsically part of the HPM technology program, and it encircles non-reconfigurable FMS as the previous step for reconfigurable RMS. Furthermore, in the implementation of RMS, other HPM programs should also be considered, when looking to get high performance in a multidimensional way. This Fig. is only an illustrative model, and draws its variables mainly from the studies reviewed. As such, it needs to be fleshed out in greater detail and better grounded in theory.

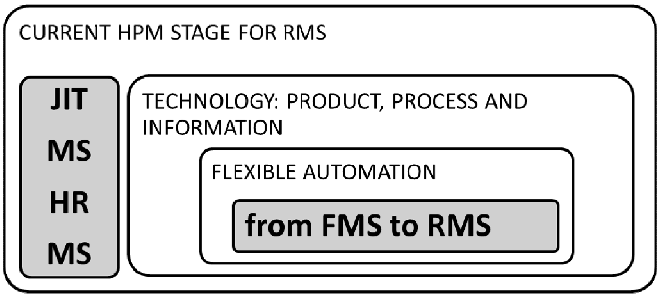

Fig. 3 General model of transition from FMS to RMS

Thus, this research provides significant support for the proposed HPM framework. As stated in Proposition 1, there are certain conditions of HPM programs link to FMS. This research provides support for Proposition 1: there were significant findings in every study on the linkages of JIT, HR, TQM, MS and other T practices with FMS.

The evidence of technology practices between the variables as proposed in Proposition 2 also found support in the research. These last practices positively impact performance dimensions, giving evidence to Proposition 3. There was also evidence that FMS by itself does not completely impact all performance dimensions offered by RMS, finding support for Proposition 4. Finally, Proposition 5 stated that plants are looking for performance dimensions offered by RMS, which they were, except for on time NP launch. It may require furthering testing the impact on this dimension from the combination of not only FMS and other technology practices, but also the other HPM programs found here to have links with FMS (e.g. JIT, TQM, etc.)

VII. Conclusion

RMS e1ectiveness is critical in current environments of economic and financial crisis that promote increasing deployment of technological initiatives due to constant market changes. Unfortunately, mere existence of technology is not sufficient. It has to be imbibed into its contingent context in order to be e1ective. While there has been substantial research on technology e1ectiveness, RMS electiveness in OM has not been reviewed. This article takes the modest step of presenting a synopsis of RMS e1ectiveness from a perspective of FMS and HPM research that has been published in major journals associated with the management sciences. This research is interpreted in light of a broad HPM based framework that espouses notions of "links and contingency" between manufacturing initiatives. Thirty three models are reviewed and it is argued that these models provide a foundation upon FMS and its link to HPM programs. In general, there seems to be support for the validity of the interactions between not only FMS and other technology practices, but also JIT, TQM, MS and HR. Therefore, it is apparent from this review that FMS technology is not and cannot be implemented independent of its environment. Thus, groups examining relationships were summarized and meta-analyzed in an attempt to provide a more integrated perspective. There was a major amount of support for the interrelationships presented in the HPM model, providing strong validation for it as presented in Propositions 1-5. The findings consistently support JIT, TQM, MS, HR, FMS, and other technology practices as important parameters for RMS performance. Performance dimensions which will be delivered by RMS were already being targeted by sets of non-reconfigurable practices such as FMS and the rest of HPM practices and programs seen here. They can however be improved and extended with the consideration of time and changes. Although HPM groups were evaluated on their common practices and dimensions related to RMS, finding that the "links and contingency" notion is also supported, the limitations of this research make it difficult to compare the models and their empirical results. Hence, these limitations bring opportunities and help to identify insights for further research. Therefore, for starters, Propositions 4 and 5 needs more extensive empirical examination of performance through testing a combination of all HPM programs involved.

Besides, a HPM framework for further examining FMS in its context will lead to better theory building that can allow examining results across itself. The use of HPM models for exploring the balancing of the various HPM levers with FMS will then allow researchers to develop a "theory of implementing, operating and managing RMS".

The research summarized here has created a foundation for such a theory. Hence, a research plan, along with a RMS research model, has been proposed with the hope of facilitating future work in reconfigurability of imminent and growing importance. It shows that plants may evolve from FMS to RMS. This paper believes that the field will better progress with development of such a paradigm for RMS implementation, and empirical examination of many FMS technologies and their level of "link and contingency" with their context will further advance research in this realm.

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