International Journal of Engineering & Scientific Research
Vol. 6 Issue1, January-2018,
ISSN: 2347-6532 Impact Factor: 6.660
Journal Homepage: http://www.esrjournal.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities

Development and future trends in Reconfigurable Manufacturing System

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Abstract:
In order to globalization of market, today's manufacturing sector must be highly responsive that rapidly can respond in tune with current markets scenarios. In the mid of 1990, Reconfigurable Manufacturing Systems (RMS) were introduced to face with increasing global market surges, unanticipated product changes through reconfiguration at machine level and system level .in this paper we discussed the characteristics and principal of RMS and different types of manufacturing flexibility. Finally, the paper concludes with future gaps for RMS that will help researcher, academians, and other concerned person involved in this area to carry out further research.
Keywords: reconfigurable manufacturing system (RMS), manufacturing flexibilities, flexible manufacturing system (FMS), dedicated manufacturing system(DMS).

1. INTRODUCTION

The world of manufacturing sector has changed drastically over the most recent 100 years in response to cope rapid product changes, high product variety, and customised product and also to face the challenges on economic and social scale. Malhotra et al. (2009) discussed **different types of manufacturing system like dedicated manufacturing system(DMS), flexible manufacturing system(FMS) to face these challenges. European manufacturing companies have a strong position to overcome customised product solution but still they are not fit for mass production and they lose market share (Westkamper 2006). In the 1960, lean manufacturing principal implemented by Japanese manufacturing company. Global competition of manufacturing marker that began in 1990 changed the manufacturing sector. Since then, frequently introduction of new product , unanticipated customer demand were the major challenges parameter for manufacturing companies. Therefore , manufacturing industries must be designed a new class of manufacturing system to addressed these issues'. The development of manufacturing system paradigms has been classified in to five stages as shown in figure 1.In this direction, Dr. Koren proposed a new class of manufacturing system known as reconfigurable manufacturing system. In 1996, U.S.Nationaal Science Foundation (NSF) was sanctioned this proposal to form an research centre for RMS known as ERC-RMS. This ERC-RMS was established at University of Michigan. The developed manufacturing technologies were successful**

implemented in General Motors, U.S Automotive industries, Ford to increase their responsiveness (Koren 2013). In the last 50 years the manufacturing companies implemented dedicated manufacturing system and flexible manufacturing system.

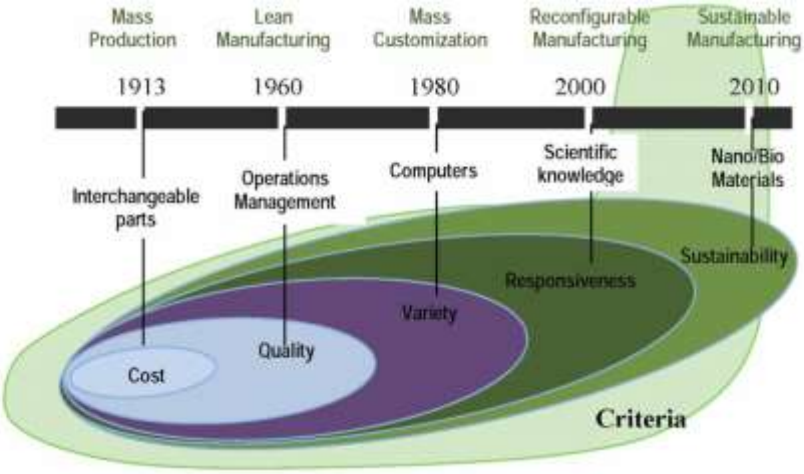

Fig. 1 Evolution of manufacturing system (Koren and Ulsoy 1997)

Dedicated manufacturing system are specially designed for mass production at a very low cost with fixed automation. Therefore ,the structure of DMS is fixed. Therefore, we cannot changed the machine structure neither to produce variety of product nor to increase the system throughput(volume expansion). Suppose, if the market demand is very high, the DMS cannot full fill high throughput and manufacturing company will lose sale opportunities and market share (ElMaraghy 2006)**. So we can say, DMS cannot face the varying demand problem.** The other manufacturing system known as flexible manufacturing system is generally used to produce variety of product as compared to dedicated manufacturing system. But the productivity of flexible manufacturing system is very low as compare to RMS (Hasan et al., 2014). In 1970s, CNC machines have been developed the creation of flexible manufacturing system. The FMS consists of computer numerical control machine (CNC) and programmable automation machine. The investment cost of FMS is very higher than DMS. Due to high investment cost of CNC machine, it becomes an important economic issues. Reconfigurable manufacturing system is created by basic modules arranged efficiently and effectively. Its objective is to provide the functionality and capacity exactly when needed. It is a special features that neither a dedicated manufacturing system nor an FMS possesses. The system configuration of reconfigurable manufacturing system can be similar to dedicated or flexible manufacturing system, or a combination of both. The capacity and functionality of reconfigurable manufacturing system lies between dedicated manufacturing system and flexible manufacturing. Reconfigurable manufacturing system concepts were proposed by Koren et al. in 1999. RMS can also achieve agility and sustainable manufacturing (Garbie 2013).In this paper, we discussed the core characteristics and design principles of reconfigurable manufacturing system. Based on these, principles, possible futures scopes of RMS are discussed.

2. RMS Characteristics

Six core features of RMS that are summarized as below. These includes modularity, scalability, mobility, diagnosability, integrability,automability (Bi et al. 2008, Koren and Shpitalni 2001, Mehrabi et al. 2000). By using these core characteristics, we can drastically reduced manufacturing time, machine set-up time, ramp up time, and reconfiguration cost, tool change cost (TCC), machine usage cost (MUC), tool usage cost (TUC), no of set-up change cost (SUC) etc. today manufacturing company like aerospace, beverage, automobile have been successfully used these concepts- which have enhance their system responsiveness and the competitiveness of manufacturing enterprises(Koren 2013).

RMS core characteristics	Interpretation
Modularity(technology related)	All system elements are designed to be modular(both hardware and software components)
Scalability(volume related)	It is easy to enlarge and downsize the production system as per market requirement
Mobility(technology related)	It is easy and quick to move and install modules part and production system
Diagnosability(product related)	It is quick to easily identified the source of quality and reliability problem
Integrability(strategy related)	Modules are easy to integrate
Automability(technology related)	A dynamics level of automation is enabled

2.1 Scalability

Incrementally scale or shrinkage the system capacity and production capacity for higher or lower production capacity by reconfiguration is known as scalability. Scalability is a sub factor of reconfigurability. In manufacturing system, the system throughput is directly depends upon the total no of machine. We can change system capacity by adding or by removing machine in an existing manufacturing system (Wang and Koren 2012).This factor play a vital role in the implementation of RMS. Space availability is also effect on the system capacity. If there is no space available for utilizing of a new adding machine, we cannot enhance the overall system capacity. After adding a new machine, proper utilization of machine is important factors. For this, line balancing technique is generally used which also affects the system scalability? The main objective of line balancing is to distribute manufacturing operational tasks over the different workstation so that ideal time of different machine is significantly reduce and flow of manufacturing operation is continuous i.e. high volume production rate (maximum throughput).Therefore, line balancing for each configuration also affects the system scalability. Forecasting of market will indicate future trends in customer demand and product variety. So many factors such as, work shift policies, planning for increase and decrease in system capacity (scalability) are based upon the market forecast and in turn effect the production planning of manufacturing system. So ,we can say, the following sub-parameters such as, total no. of machine, forecasting of market demand, extra floor space for adding new machine, line balancing of each operation in manufacturing work station etc. are play a vital role while implementation of capacity scalability planning in RMS design at design stage.

2.2 Modularity of manufacturing system

As uncertainty in market and variety of product design and demand, today manufacturing industries are using modular machines (reconfigurable machine module) with modular control system, variable dimension modules, modular process architeraure etc. to modify machine structure so that we can changed machine structure among different types of manufacturing station for different manufacturing tasks. Reconfigurable machine play a significant role for an RMS to achieve high level of reconfigurability(Bi et al. 2008) .Modularity based manufacturing system is purely based on replacement, readjustment and exchangeability concepts, that can be reconfigured for wide range of variety of product families to meet specific customers demand. Considering the automobile industries as an example, the component design, and structure of any car are changing from time to time according to customer's requirement so these company must now be ready to change itself by adding and removing modules. Therefore modularity is one of the vital factors in designing of any manufacturing system at initial stage. Modularity is inversely proportional to the number of connections between different components. Therefore, loosely coupled system has higher modularity value than the compact system (Tiwari et al. 2011). Modular structures of RMS provide continuous production with the modification of latest technology, quickly machine hardware and software changes, increased feasibility of machine component changes and easier product diagnosis. Modularity of RMS would be more if it is capable of handling a variety of modular machine parts and components. Modularity of RMS is highly depending upon the interface between electrical, mechanical and software modules to allow fast integration. Therefore, modularity can be changed by using modular parts of reconfigurable machine and it is closely related to scalability. So, modularity parameter also plays a vital role in implementation of RMS at design stage.

2.3 Integrability of RMS:

The ability to integrate different system and subsystem components modules rapidly is called integrability. Integrability of manufacturing system can be achieved at two different levels (ie. At machine level and at system level).Integration of machine hardware and software components, automatic changing of tool magazine of reconfigurable machine tool, machine code (G-and M code), no. of spindles are the main factors of integrability at machine level and optimal layout, process planning, factory software and workshop selection are main factors at system level which effects integrability of manufacturing system.

2.4 Mobility

Li et al 2009 defined the mobility as a reconfigurability characteristic in terms of easiness of moving around and relocating machine elements and subsystems or movement of manufacturing equipment. Mobility could be achieved by placing machines on rollers (ElMaraghy and Wiendahl, 2009; Nyhuis *et al.*, 2006) or by designing machine tools and other production machines with a three-point base that allows them to be readily lifted and moved by a crane or fork-lift truck (Groover, 2001).

3. RMS concept and design issues

The main aim of any manufacturing system is to transformed raw material in to finished products but its ultimate objective to achieve or gain market share and profit. Any manufacturing interties can sustain in this turbulent and uncertain market environment only if this objective is fulfilled. Ishii et al. 1995 discussed some critical requirement for reconfigurable manufacturing system such as short lead time, more variants, low and fluctuating capacity and low price. Spicer et al .2002 discussed the design principles for RMS to reconfiguration speed and consequently speed of responsiveness. By using these principles we can esily remove unpredictable market chages, unexpected product variation problems. The more these principles are applicable to a manufacturing industries , the more reconfigurable that manufacturing system is. These three reconfigurable principles are as given below.

1. An RMS system provides adjustable production resources to respond to unpredictable market changes and intrinsic system events:

• RMS capacity can be rapidly scalable in small increments.
• RMS functionality can be rapidly adapted to new products.
• RMS built-in adjustment capabilities facilitate rapid response to unexpected equipment failures.

2. An RMS system is designed around a product family, with just enough customized flexibility to produce all members of that family.

3. The RMS core characteristics should be embedded in the system as a whole, as well as in

RMS consists of reconfigurable machine tool, reconfigurable assembly machine, reconfigurable fixturing system, reconfigurable inspection machine, reconfigurable material handling system and reconfigurable machining system, reconfigurable hardware and software. Reconfigurable machine tool is a heart of RMS(Koren2010a). Koren and Kota 1999 was developed the world first patent of RMT and exhibited in 2002 in Chicago at world international manufacturing platform. since then consistent RMT has been a major focal point for RMS. Development of RMTs also plays roles for achievement of Industry 4.0. A system in Industry 4.0 is typically composed of CPSs with smart products, smart machines and augmented operators associated ina network through Internet of Things (Gilchrist 2016) In the response to this challenges, different types of RMT models or prototypes have been developed between 2000 to 2017(Dhupia et al. 2007; Gwangwava et al. 2014, Ponce et al. 2015, Padayachee and Bright 2012;).Mehrabi et al. (2000 focused on some design issues of any type of RMS. Its critical issues include architecture design, configuration design, and control design. Architecture design determines system components and their interactions. System components are encapsulated modules. Interactions are the options when the modules are assembled. RMS architecture has to be designed to produce as many system variants as possible, so that the system can deal with changes and uncertainties cost-effectively. Architecture design is involved at the phase of system design. modularity, scalability, convertibility, integrability are the main features of architecture design of RMS(Zong ang Zeng 2012) .further , he summarized the generic principles of reconfigurable machine tool. According to him , RMT should be consist of reusability, reconnection, adaptation, unification and separation features. In this research field, Padayachee and Bright 2012 developed a modular reconfigurable machine(MRM) to work as a lathe configuration and milling configuration. in this further direction Meng et al 2014 developed a machine of square foot machine which is based on a high level of changeability. Bie 2011 developed a reconfigurable parallel-kinematics machine(PMK) which is generally used a modular components like links, joints, actuators, tool holders etc as shown in figure 2 .

Figure 2 Virtual and physical models of 5-axis PKM (Bi 2011)

Configuration design determines system configuration under given system architecture for a specific task. A configuration is an assembly of the selected modules; a configuration can fulfill the given task optimally. Configuration design is involved at the phase of system application. Many mathematical tools have been used for optimal design configuration for RMT. Spicer, Yip-Hoi, and Koren (2005) developed a mathematical approach to determine the optimal number of modules to be included in a scalable reconfigurable machine. Control design determines appropriate process variables (joint displacements and velocities, etc., of a joint module), so that a configuration can be operated to fulfil the task satisfactorily. Control design is involved at the phase of system operation.

4. Flexibility in RMS

Flexibility is a very strong tool, which is generally used to change the capacity management in reconfigurable manufacturing system. By using flexibility conceepts, the manufacturing time of different operation, cost of the system and effort may be reduced (Toni and Tonchia, 1998). Many Researchers defined flexibility, as “the ability of a manufacturing system to deal with rapidly changing situations or instability caused by the environment” (Gupta and Goyal, 1989). ElMaraghy,2006 , Malhotra et al.,(2010), Joseph, and Sridharan(2011) explained the different types of flexibility and their measurement. They are machine flexibility, routing flexibility, material handling flexibility, operation flexibility, process flexibility, product flexibility, volume flexibility, and expansion flexibility, sequencing flexibility Control Program flexibility, production flexibility. Malhotra et al.,(2010) highlighted the merits, demerits and applications of RMS and FMS.

With the help of routing flexibility we can increase the performance of manufacturing system (Caprihan and Wadhwa, 1997). Barad and Sapir (2003) suggested that routing flexibility should be the ability to make a product by alternate routes. According to Chang (2007), routing flexibility provides an answer to the strategic needs of meeting customer requirements and also provides the system with the capability to expand its capacity when needed. Chan, (2001) presented a detailed study of routing flexibility and considered “make span time”, life cycle time, mean time to failure, average lead time as key performance measures. Ali and Wadhwa (2005) studied the effects of routing flexibility on the performance of reconfigurable manufacturing system. They found that partial routing flexibility gave much better performance than total routing flexibility at a different buffer capacity.

Routing flexibility may be generally used to solve the scheduling problem in reconfigurable manufacturing system. In RMS, more than one operations are performed in a single cycle, therefore, routing flexibility is an important performance parameter for reconfigurable manufacturing system. Lin and Solberg (1991), indicate that flexible processing could reduce mean flow time while increasing system throughput and machine utilization. Barad (1992) investigated the relative impact of versatility as a physical characteristic and operating strategies on RMS performance. Lun and Chen (2000) developed a simulation-based framework for part routing decision in RMS scheduling using a holonic concept by establishing cooperation among the identical workstations and other resources or information systems.

Garavelli (2001), presented a mathematical simulation approach which is used to analyse the performance of different manufacturing systems, each manufacturing system is characterized by a specific degree of flexibility, which is known as routing flexibility. The researcher finds that instead of complete flexibility, a system with limited flexibility performs better in terms of lead time and work in process. Mohamed et al. (2016) presented a study wherein the relationship between the degree of machine flexibility and the level of system performance are analysed. Kumar (1987), proposed flexibility measures based on the concept of entropy. Four measures and the properties of these measures have been described. These measures have been illustrated in measuring routing flexibility, operations flexibility and loading flexibility in a manufacturing system. He developed a measurement of flexibility in manufacturing systems for mass customization. This measurement measures not only the impact of manufacturing technology hardware but also the impact of the product design and process design.

The definition of machine flexibility is given by Browne et al., (1984), as “the ability to carry out different operations with limited set-up times”. It may reduce the excessive workload while changing from one manufacturing operation to another manufacturing. In machine flexibility, machine setup time is very important performance parameter, it includes tool changing time, part fixing time, and part-programme substitution, etc. Thus, Machine flexibility directly affects the performance of reconfigure manufacturing system.

Singholi and Ali(2013) proposed a new mathematical simulation method know as Taguchi's simulation method. This method may generally used to compare the various types of flexibility which directly affects the performance of reconfigurable manufacturing system. He also explained the other types of performance parameter of an RMS.This section presented the literature pertaining to reconfigurable manufacturing system, which starts from its definition and extended to different types of flexibility, and its dimensions and approaches, mathematical models for addressing the performance parameter for reconfigurable manufacturing system that can be applied to enhance the system performance.

The productivity, supportability (Asjad et al., 2012, 2013, 2014, 2015, 2016), quality, reliability and related performance issues can be an important aspects for reconfigurable manufacturing systems. But still, these performance issues are addressed at the initial stage or design stage because in this stage majority of life cycle cost is involved.

5. Observations

The observations/gaps that are extracted from the literature review are summarised below:

1. Relatively less research work is done on efficient approaches for obtaining the optimal configurations, attaining the optimal selection policy, and getting the optimal performance measure.
2. Less focus on evaluating the effect of flexibility types such as process flexibility, operational flexibility, volume flexibility, etc. on performance of manufacturing system (productivity, etc.).
3. Reliability, maintainability, maintenance schedule, inventory level, resources for reconfigurable manufacturing system needs to be explored in the context of design stage.
4. More work is required to development of systematic approaches and fundamental principles to identify root-causes of components failure, and quality and process variations in RMS.
5. A lot of work is required to develop strategies based on artificial intelligent and machine vision to facilitate the process of part family formation.
6. More work is required to be conducted using wide set of cell formulation problems in order to study the significance of considering there configuration effort and the routing flexibility.
7. Lack of relevant data and optimization models (framework) for analysing the quality, reliability, availability, supportability and maintenance issues during design and development phase of RMS.

The next sub-section deals with the current practices on the basis of which the directions for future research are proposed

6. Conclusion

The paper received the research issues that are set in the beginning of work, which are fulfilled through literature review, on the basis of which potential direction and area for future research has been suggested. However, further efforts are needed to determine empirically impact of reconfigurable manufacturing system parameter on system performance while addressing the individual support issue. This work is expected to motivate designers, researchers, engineers and others persons involved in the area of manufacturing system, to implement and understand its importance. It is hoped that the research presented in this paper will pave the way for more concerted efforts in the field of manufacturing systems.

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