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Reconfigurable Manufacturing and Beyond

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Reconfigurable Manufacturing System (RMS) technology enables the design of a "living," evolving factory that can be rapidly and cost-effectively reconfigured exactly when the market requires a change. The RMS is necessary for sustaining profits in the face of market fluctuations caused by global competition in the 21st Century.

RMS may be applied to manufacturing systems for large volume production, such as those used in the auto industry, and can be applied to a small cell of machines, or even to a single machine. The concept in all these applications is the same – purchase exactly the equipment that you need, with the option to change it exactly when your needs will change. Changes may be in the functionality of the equipment or system (i.e., features), and in their capacity (products per day). Changes may be also needed in the reallocation of tasks among machines. All these types of changes require reconfiguration, of hardware and software. The reconfigurable system and reconfigurable machines as well as their software must be designed at the outset to be reconfigurable, quickly and cost-effectively.

A reconfigurable machine and a reconfigurable manufacturing system (i.e., the process) are designed to produce a product family, rather than to produce just a single product (dedicated lines) or to produce any type of product (full flexible systems). During the expected 15 – 20 year RMS lifetime, the manufacturing system will produce many products, all of the same product family. This will impose some new constraints on new product designers, who will have to design a new product of the family with the structure and capabilities of the manufacturing system in mind. In other words, the new product designer will have to design "process-driven products." However, since the RMS could be adapted to the manufacturing of new products of the family, this new constraint is very mild. Basically, the functionality (and sometimes also the production capacity) of several machines in the manufacturing system will have to be reconfigured to fit the production of the new product.

We envision that during the lifetime of the RMS its functionality will be reconfigured several times to fit new products designed to be produced on the RMS, and its production capacity will change according to market demands. A ramp-up period to re-calibrate the machines must follow each reconfiguration. Achieving a short ramp-up period is very critical with RMS since there are many ramp-up periods during the lifetime of the system, as shown in Figure 1.

Shorter ramp-up periods are achieved with RMS technology by in-process non-dedicated inspection that replaces the current off-line inspection done with CMMs. Reconfigurable in-process inspection machines (RIMs) embedded in the RMS may be utilized for this inspection. They can detect small porosity defects on machined parts, and measure surface straightness, parallelism, geometric features, as well as inspect cylinder bores. The optimal placement of such in-process inspection equipment could be determined as part of the product design phase by using RMS technology.

The vision of the reconfigurable manufacturing paradigm may be summarized as follows:

Exactly the Capacity and Functionality Needed . . .
. . . Exactly When Needed

A manufacturing system that can be rapidly and cost-effectively reconfigured exactly when the market requires a change, offers an important economic advantage to companies.

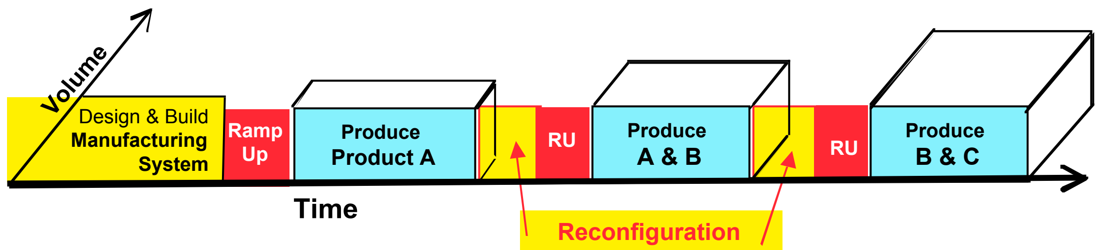

Figure 1. During its lifetime the RMS will be reconfigured many times to adapt to the market in terms of production volume (capacity) and type of goods produced (changed functionality)

The definition of a reconfigurable manufacturing system is, therefore, as follows:

A Reconfigurable Manufacturing System (RMS) is one designed at the outset for rapid change in its structure, as well as its hardware and software components, in order to quickly adjust its production capacity and functionality within a part family in response to sudden market changes or intrinsic system changes.

RMS Characteristics

At the heart of reconfigurable manufacturing is a set of core characteristics. Our premise is that to enable a high degree of system responsiveness to market needs, several core characteristics, which are defined below, should be embedded in the reconfigurable system at the design stage.

Modularity – the compartmentalization of operational functions and requirements into quantifiable units that can be transacted between alternate production schemes to fit a given set of needs.

Scalability—the ability to easily change existing production capacity by rearranging an existing production system, and/or changing the production capacity of reconfigurable components (e.g., machines) within that system.

Integrability – the ability to integrate modules rapidly and precisely by a set of mechanical, informational, and control interfaces that enable integration and communication.

Convertibility—the ability to easily transform the functionality of existing systems, machines, and controls to suit new production requirements.

Diagnosibility—the ability to automatically read the current state of a system and controls so as to detect and diagnose the root-cause of defects, and subsequently correct operational defects quickly.

Customization – the ability to adapt the customized (non-general) flexibility of production systems and machines to meet new requirements within a family of similar products.

When these characteristics are embedded in the system design, a high degree of reconfigurability is achieved. Furthermore, they enable the RMS to serve as a **cost-effective** compromise between the low productivity but high flexibility of FMSs, and the ultra-high productivity but zero flexibility of dedicated lines. Therefore, some people refer to RMS as "lean FMS."

The cost-effectiveness of RMS is achieved through:

- Adjustable resources that enable system scalability in response to changing market demands, and system convertibility to new products of the same part family. Resources may be adjusted at the system level (e.g., adding machines) and at the machine level (changing machine hardware and control software).
- Customized flexibility for a part family that can allow for (1) optimal mix between CNC and dedicated machines in a system, and (2) multi-tool operation on a CNC-type machine, thereby multiplying the productivity of the machine.

In summary, the RMS is a responsive system whose production capacity is adjustable to fluctuations in product demand and whose functionality is adaptable to new products.

Beyond Reconfigurable Manufacturing – what is next?

Reconfigurable manufacturing, which was invented at the University of Michigan in 1999, is by now an established field of research. Researchers in Europe, Canada and China have extensive research programs on RMS. The big question is what is the next paradigm in manufacturing?

The future of the Western manufacturing industries, and especially the automotive industry, does not look bright in light of the expansion of the Chinese auto industry and the emerging of an auto industry in India. Just recently, on April 21, 2005, a senior DaimlerChrysler executive, Ruediger Grube, shocked a room of journalists at the Shanghai Auto Show by disclosing that the company intended to export small cars from China to the US and Europe as soon as 2008 [New York Times, 4/22/05, p. C1]. Robert Lutz, the vice chairman of GM said that he expected at least one of China's homegrown automakers to be successfully exporting around the world in the next five years (i.e., before 2010). People are wondering – what is the manufacturing technology that will save the Western manufacturing industries, and in particular the auto industry in Europe and the US.

Saving the Western World auto industry must be done in two fronts:

1. Increasing the level of automation and enhancing in-process inspection in production lines. When goods are manufactured on highly automated production lines, the cheap Asian labor has a little impact on the product cost. Designing, building and maintaining automated plants provide high-paying jobs in the U.S.

2. Designing and producing products, and especially vehicles, in which the geographic proximity to the customer and a short delivery time are playing an over whelming role.

An example of such a product is the futuristic personalized car. The personalized car will be designed in cooperation with the individual customer, such that it fits the personal needs and taste of the customer. It will be immediately produced, and delivered in a timely manner.

A very basic example is custom kitchen design; considering room shape, size, window locations, and illumination, each kitchen starts out being different. A different individual customer who has his/her needs, preferences and taste will use each kitchen – which adds another level of difference. However, personalized kitchens in the US are made at affordable prices.

The technique to achieve low cost is to divide the product design process into two phases, as shown in Figure 2.

The first phase includes the design of the building blocks, or modules, of the product (number, shape, color, material, etc.), and a general open-architecture that specifies where modules could be anchored on the chassis to provide stability and safety, and how modules will be connected and integrated with each other when considering three aspects:

- Mechanical (e.g., brackets, bolts, grooves, etc.),
- Power (electrical, hydraulic, water, etc.), and
- Information (sensor signals, computations and controls).

This product design phase is done by the manufacturer. Then the financial transaction – the sale to a customer – occurs, and then the next phase, in which personal needs and requirements are added to the product, starts.

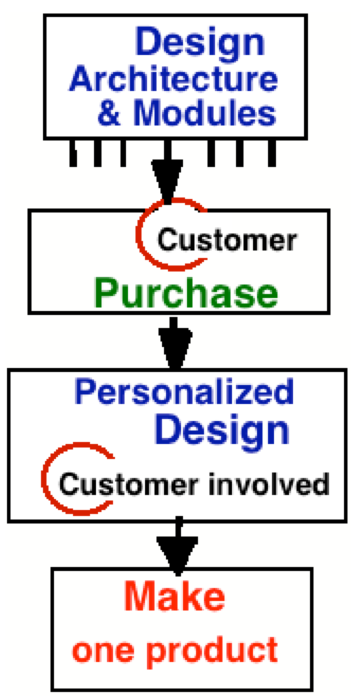

Figure 2. Product personalization includes two design phases

The second phase is the personalized design phase in which the customer is involved. Based on the "library of modules" offered, the physical constraints, and the customer preferences and taste, the personalized design is finalized, and only then the product is manufactured and delivered.

In the modular kitchen example, each kitchen would look unique, even if the basic building blocks –the kitchen modular cabinets– are coming from the same manufacturer. The modular product design methodology enables the low-cost of the product.

Ford Corp. has a Mass-Customization Department that runs a Vehicle Personalization program. This is an indicator to some confusion in the industry between the terms mass-customization and personalization. Indeed, both mass customization and personalized production are supplying products that fit the customer needs and preferences. The basic difference between the output products of the two is that in mass customization there will be similar products in the market, whereas **with the personalized production almost every product is one-of-a-kind**, but it is being sold at affordable price. The internal kitchen design is a good example that explains the concept.

For many years the interior of the airplane is designed by the customer (i.e., the airline). The main modules are the passenger seats, the galleys and the lavatories. The airlines make the decisions regarding the spacing between rows, the safety rails to which the seats are tied, the location of the galley (kitchen), etc. Some airlines, have special security requirements that also change the interior design (El-Al for example, has a small secured corridor between the pilot cabin and the passenger cabin to protect the pilots). Each airline chooses the color of the cabins. In the end of the day the interior of the planes do not look so different from one airline to another, but still the airplane interior is designed exactly as the customer wants it.

Personalization of Vehicle Interior

We predict that by 2025 the interior of luxury cars, minivans and SUVs in Europe and the USA will is designed by the customers in the same way that the interior of airlines is designed. The interior of the car will be an open space that the customer will have to design subject to safety constraints. There will be a set of modules (e.g., different car seats, shelves, entertainment equipment, panels, lights, handles, etc.) that the customer will have to select from and compose according to his/her preferences. As a result, the interior of cars of the same model will look different from each other.

The requirements of a woman with two small children sitting in the back of the car and driving in the city, are different than those of businessmen who are going on long trips. An old person who is usually sitting in the back would like to have in the back of the car a comfortable seat and not a 3–passenger bench. A short woman would like a different design of the driver panel (selected from a set of given modules) than a tall man that can reach further features in the panel. Some people would like to have a car seat with a folding shelf, like in airplanes, so they could work with a laptop during long trips.

Furthermore, the trend will be of reconfigurable interiors of vehicles that will go beyond of folded seats, to the removal and replacement of seats according to the changing needs of the users. For example, installing a small fridge instead of a car seat for long trips in hot days will become the practice.

We predict that 20 years from now, by the year 2025, the customer will have the interior of the car as an open space. The customers will design the interior of their car. The input will be the length of the hand of the customer and his/her height. The computer will show a virtual reality image of the interior space and lead the customer through step-by-step selection of the modules (seats, dog baskets, panels, etc.) from a given database. Perhaps, in the end, the interior of the vehicles would not look that different from each other, but the customers will have at least the perception that they designed their own vehicles. And perception counts and sells products.

To achieve efficiency in personalized production, industry must pursue a whole new paradigm in the design and operations of manufacturing systems. Manufacturing systems must be reconfigurable and flexible enough to provide acceptable levels of response to demand, and contain reconfigurable inspection facilities to verify the customers' exact orders.

To summarize, to continue to build cars in the U.S. we need (1) fully automated production lines, and (2) designing and building vehicles that are tailored exactly to customer needs and preferences. These personal vehicles should be produced at the proximity of the target market, and produced at close to mass-production cost.

The consumer goods manufacturing industry should start planning for Market-of-One products that are sold at affordable price.

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