Procurement of Reconfigurable Assembly System: A Justification for Effective Production Ramp-up Planning

Zulfiqar Ali-Qureshia*, Waguih H. ElMaraghyb

aIndustrial & Manufacturing Systems Engineering Department, University of Windsor, N9B 3P4, Canada
bHead Industrial & Manufacturing Systems Engineering Department, University of Windsor, N9B 3P4, Canada.

*Corresponding author. Tel.: +1-253-3000-0000; fax: +1-253-3000-0000. E-mail address: aliqur@uwindsor.ca

Abstract

Production ramp up is an important activity in manufacturing through which the capacity to produce necessary product variety, size, type, model, quantity, quality and feature is achieved. By introducing rapid changes in the product at manufacturing system levels, value for customers is created to meet target market needs, free market economy is the only solution to meet the changing dynamics of the market, and keeping a competitive edge in the market for staying in business. In this context, system dynamics has been used to address the volume and capacity yield issues. Other core issues of production systems are automated and manual assembly units in order to manage an effective and fast production ramp-up to respond rapidly to the niche market changes in the demand cycles. This paper contributes and attempts to describe the dynamic behavior patterns involved in managing the aforesaid challenges due to assembly by means of manual and automated assembly processes. Besides, this research concludes that procurement of reconfigurable manufacturing systems are essential for having effective and fast production.

© 2014 The Authors. Published by Elsevier B.V.
Selection and peer-review under responsibility of the International Scientific Committee of “The 6th CIRP Conference on Industrial Product-Service Systems” in the person of the Conference Chair Professor Hoda ElMaraghy.

Keywords: Ramp Up, Reconfigurable Assembly, Production System, Manual Assembly, Fixed Automation;

1. Introduction

Continuous technological advancement has increased the demand for variety and features in the products which in turn have shortened the product life cycle in the market. Rapid change of technology requires equipment which can manage to manufacture complex products within a shorter period of time, also require changes in their hard and soft enabler with every change in system capacity, design feature changes or fabrication and process changes. These relatively new requirements for more customized flexibility which accommodates sudden changes in production has lead to the concept of reconfigurable manufacturing systems (RMS). The production ramp-up process can be considered as an interconnection between product design and first pass to full production. Therefore, manufacturing ramp-up affects the company’s economic position either to have an early market access or otherwise. As we see in the case of BlackBerry®, iPhone and Samsung Galaxy competition. In spite of using the best, available to the companies, technologies in engineering design and manufacturing systems, issues may arise due to insufficient agility or rapid control of ramp up issues. “Designing a manufacturing system to achieve a set of strategic objectives involves making a series of complex decisions over time. In practice, designing the details of manufacturing systems (equipment design and specification, layout, manual and automatic work content, material and information flow, etc.) in a way that is supportive of a firm’s business strategy has proven to be a difficult challenge. Because manufacturing systems are complex entities involving many interacting elements, it can be difficult to understand the impact of detailed, low-level deficiencies and
change the performance of a manufacturing system as a whole” [1].

2. Background

Earlier published research has suggested [2] that long ramp-up time for production system is undesirable and hard and soft enabler of the manufacturing system do not coordinate effectively, then problem will persist. For instance, core trouble areas are machinery, electronic and troubled software, but some main reasons behind it are the Design for Assembly (DFA) and the Design for Manufacturing (DFM). Furthermore, technology upgrades or design modifications, for part or feature or new user interface causes of time consuming ramp-up process. In fact, long testing of hardware in combination with control software is considered primarily a complex mechatronic issue. The review of ongoing research relating to stream-of-variation methodology shows that the variety and the market pull which are core aspects for the product accelerated acceptance by the customers are not considered [3]. However, how control software will work for both system design and later production is explained in [4]. The concept presented is based on scalable simulation a method for the economic application of virtual commissioning. Recently [5] an optimization technique which forecast those personnel requirements during ramp-up by taking into accounts the dynamic planning variables and organizational basic conditions, has been presented. This helps decision maker to calculate the necessary manpower for every single ramp-up phase and to realize it to economic optimum. Moreover, the scalability of production principles for a fast ramp-up; as well as advanced methods, processes and tools like a 3-cycles, is used to note the unintended disturbances and deliberate changes on overall maturity in [6] it also describes the risk during ramp-up. Next, an analytical solution for capacity planning which is based upon markov theory is presented [7] and the optimized solution takes in to account the effects of ramp-up phenomenon. But their analyses prove that ignoring the ramp-up effect in the decision process can lead to significant increases in overall costs. In fact their solution is based on optimal boundaries representing the optimal capacity expansion and reduction levels, explicitly considering production ramp-up. Further research describes [8] that “Companies that introduce new products quickly have been shown to be better performers. The effectiveness of the new product introduction process is critical to their performance. Production ramp-up is a necessary phase of new product introduction and both planning and execution need careful consideration especially for engineered products which are generally typified by design, purchasing and production complexity. Better understanding of the issues and more effective modelling of options should lead to more predictable and quicker ramp-up”. Moreover, in [9] the knowledge base which is acquired helps and initiates guidance in reality to develop an architecture for a modelling tool for engineering product ramp-up. This is in fact a review work and looks in to the issues but does not address the design and system level issues. These are important as they are directly influencing the shorter life cycle and increasing complexity of the product process at hard and soft drivers where all changes occur during the ramp-up phase. In [10] the situations of the ramp-up as described by focusing on the demand of design in developing market, suggests strategies to optimize the profit margin and as well as complexity of business processes.

Finally, Koren et al. [11] explained that reconfigurable manufacturing system (RMS) as a manufacturing system designed from the beginning for rapid change in structure, as well as its hardware and software components in order to adjust production capacity and functionality quickly, in response to sudden changes in market or regulatory requirements or in design for quality. Since, the industrial revolution, dedicated manufacturing system (DMS) has been favored for mass production, and most factories around the world make use of it. Mass production results in a low product unit price. Owing to the nature of the traditional dedicated manufacturing system, any slight change in product design may make further production of the new product on the line difficult, if not impossible. The reason is that DMS, by design, is made rigid to enhance mass production for profitable and cost-effective purposes. But this type of manufacturing system can only be effective in a stable market. Today’s market is highly volatile competitive, dynamic, and customer-driven. In fact, a market scenario can be characterized by increased customer demand for a wider variety of products in unpredictable quantities. The basic idea of the reconfiguration philosophy is to achieve the exactly desired capacity and functionality exactly when needed by means of characteristics modularity, scalability, integrability, convertibility, diagnosability and customization as explained by Wiendahl, et al [12] and ElMaraghy, H.A. [13]. In fact the reconfigurable manufacturing system accommodates the gap between single product, high volume yields, and multi-product mix in low volume batch production needs. Also like mass production for a single module of a similar family parts high production turn out is achieved by scaling up capacity at high production rates just like the dedicated machines based production lines in case of mass scale production. Batch production is possible because of the ability to rapidly convert the lines between products in the family, a capability absent in traditional DMS based lines. Finally, in this context related works of Sterman, J.D. [14], have also been studied to understand the extent of the issue so as to be described by using system dynamics approach.

3. Fixed Assembly Automation Scenario Study

For this step of the research consider which type of the cost will influence more when it comes to the assembly of the parts in our case study. We first consider the fixed automation case, in this regard we have the following key variables and parameters as define in Table-1 along with the model and its key attributes as shown in the figure 1 and figure 2. Let us consider that the

- **Initial time** $T_i = 0$
- **Final time** $T_f = 10$ Year
- **Time Step** $dT = 0.125$

- **Companies that introduce new products quickly have been shown to be better performers.**
- **The effectiveness of the new product introduction process is critical to their performance.**
- **Production ramp-up is a necessary phase of new product introduction and both planning and execution need careful consideration especially for engineered products which are generally typified by design, purchasing and production complexity.**
- **Better understanding of the issues and more effective modelling of options should lead to more predictable and quicker ramp-up.**
- **Moreover, in [9] the knowledge base which is acquired helps and initiates guidance in reality to develop an architecture for a modelling tool for engineering product ramp-up.**
- **This is in fact a review work and looks in to the issues but does not address the design and system level issues.**
- **These are important as they are directly influencing the shorter life cycle and increasing complexity of the product process at hard and soft drivers where all changes occur during the ramp-up phase.**
- **In [10] the situations of the ramp-up as described by focusing on the demand of design in developing market, suggests strategies to optimize the profit margin and as well as complexity of business processes.**
- **Finally, Koren et al. [11] explained that reconfigurable manufacturing system (RMS) as a manufacturing system designed from the beginning for rapid change in structure, as well as its hardware and software components in order to adjust production capacity and functionality quickly, in response to sudden changes in market or regulatory requirements or in design for quality.**
- **Since, the industrial revolution, dedicated manufacturing system (DMS) has been favored for mass production, and most factories around the world make use of it. Mass production results in a low product unit price. Owing to the nature of the traditional dedicated manufacturing system, any slight change in product design may make further production of the new product on the line difficult, if not impossible.**
- **The reason is that DMS, by design, is made rigid to enhance mass production for profitable and cost-effective purposes. But this type of manufacturing system can only be effective in a stable market. Today’s market is highly volatile competitive, dynamic, and customer-driven. In fact, a market scenario can be characterized by increased customer demand for a wider variety of products in unpredictable quantities.**
- **The basic idea of the reconfiguration philosophy is to achieve the exactly desired capacity and functionality exactly when needed by means of characteristics modularity, scalability, integrability, convertibility, diagnosability and customization as explained by Wiendahl, et al [12] and ElMaraghy, H.A. [13]. In fact the reconfigurable manufacturing system accommodates the gap between single product, high volume yields, and multi-product mix in low volume batch production needs. Also like mass production for a single module of a similar family parts high production turn out is achieved by scaling up capacity at high production rates just like the dedicated machines based production lines in case of mass scale production. Batch production is possible because of the ability to rapidly convert the lines between products in the family, a capability absent in traditional DMS based lines.**
- **Finally, in this context related works of Sterman, J.D. [14], have also been studied to understand the extent of the issue so as to be described by using system dynamics approach.**

**Table-1:**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_i$</td>
<td>Initial time (0)</td>
</tr>
<tr>
<td>$T_f$</td>
<td>Final time (10) Year</td>
</tr>
<tr>
<td>$dT$</td>
<td>Time Step (0.125)</td>
</tr>
</tbody>
</table>

---

**Note:**
- **Companies that introduce new products quickly have been shown to be better performers.**
- **The effectiveness of the new product introduction process is critical to their performance.**
- **Production ramp-up is a necessary phase of new product introduction and both planning and execution need careful consideration especially for engineered products which are generally typified by design, purchasing and production complexity. Better understanding of the issues and more effective modelling of options should lead to more predictable and quicker ramp-up.**
- **Moreover, in [9] the knowledge base which is acquired helps and initiates guidance in reality to develop an architecture for a modelling tool for engineering product ramp-up. This is in fact a review work and looks in to the issues but does not address the design and system level issues. These are important as they are directly influencing the shorter life cycle and increasing complexity of the product process at hard and soft drivers where all changes occur during the ramp-up phase. In [10] the situations of the ramp-up as described by focusing on the demand of design in developing market, suggests strategies to optimize the profit margin and as well as complexity of business processes.**
- **Finally, Koren et al. [11] explained that reconfigurable manufacturing system (RMS) as a manufacturing system designed from the beginning for rapid change in structure, as well as its hardware and software components in order to adjust production capacity and functionality quickly, in response to sudden changes in market or regulatory requirements or in design for quality. Since, the industrial revolution, dedicated manufacturing system (DMS) has been favored for mass production, and most factories around the world make use of it. Mass production results in a low product unit price. Owing to the nature of the traditional dedicated manufacturing system, any slight change in product design may make further production of the new product on the line difficult, if not impossible. The reason is that DMS, by design, is made rigid to enhance mass production for profitable and cost-effective purposes. But this type of manufacturing system can only be effective in a stable market. Today’s market is highly volatile competitive, dynamic, and customer-driven. In fact, a market scenario can be characterized by increased customer demand for a wider variety of products in unpredictable quantities. The basic idea of the reconfiguration philosophy is to achieve the exactly desired capacity and functionality exactly when needed by means of characteristics modularity, scalability, integrability, convertibility, diagnosability and customization as explained by Wiendahl, et al [12] and ElMaraghy, H.A. [13]. In fact the reconfigurable manufacturing system accommodates the gap between single product, high volume yields, and multi-product mix in low volume batch production needs. Also like mass production for a single module of a similar family parts high production turn out is achieved by scaling up capacity at high production rates just like the dedicated machines based production lines in case of mass scale production. Batch production is possible because of the ability to rapidly convert the lines between products in the family, a capability absent in traditional DMS based lines. Finally, in this context related works of Sterman, J.D. [14], have also been studied to understand the extent of the issue so as to be described by using system dynamics approach.**
### Table (1) Variables for case study

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Variable Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Labour Cost</td>
<td>Labour or man hours on machine tools for completion of given task.</td>
</tr>
<tr>
<td>Annual Production Volume</td>
<td>This is a Volume of products required to be produced per year. Usually the target goal to be achieved.</td>
</tr>
<tr>
<td>Assembly time per part of the Component</td>
<td>This is the time which is required to be worked out for assembly of part of an assembly.</td>
</tr>
<tr>
<td>Number of hours per shift</td>
<td>This is number of hours in the shift which is required</td>
</tr>
<tr>
<td>Production Yield</td>
<td>Percentage of the product passed and cleared by the quality and inspection.</td>
</tr>
</tbody>
</table>

Any instant \( T \):

\[
T = \sum_{n}^{0} 0.125 \times n + T_i \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)
\]

Where \( n = \frac{T_f - T_i}{\Delta T} \)

Whereas let us consider the annual production volume supposedly is in initial time in terms of product per year are as such \( AprVol = 25000 \)

Whereas it assumed that the average cost per station in the machine one station per part is given in terms of initial time and units of dollars as such

\[
C_{machine \; Station} = CmS = 25000
\]

Let us assumed that the Down time of the machines initial time in terms of units of minutes are assumed as per shift then we have

\[
 Down \; time \; Station = DtS = 35
\]

Let us assumed that the efficiency of the machines operator in terms of percent at the initial time is given as Efficiency of operator= \( E_{mo}=98*1/100 \)

Let us also assumed that the machine maintenance cost which is necessary and budgetary allocation for this purpose is considered at initial in terms of dollars as such Cost of machine /year =\( C_{m}=10000 \)

Similarly, consider the percentage of the acceptable products at the initial Time in terms of percents,

\[
Yield = Y = 96*1/100
\]

Now, the unit assembly cost for fixed automation at the final time \( T_f \), in terms of dollars as such:

\[
\text{Cost}_{\text{Assembly,Fix}}^{\text{Automation}}(T_f) = \int_{T_f}^{T_i} \left( CmY \times CmS \times \frac{1}{AprVol} \times Y \right) \times \frac{1}{E_{mo}} - DtS \times dT + \text{Cost}_{\text{Assembly,Fix}}^{\text{Automation}}(T_i) \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)
\]
4. Results of the Case Study

The simulation reveals the fact that with the Yield of 98% and increase of production volume to about 10 thousand will enable us to reduce the unit assembly cost compare to the other parameters provided that the conditions are not changed with regard to the influencing parameters likewise the average cost per machine and fraction of machine cost allocated remain undistributed for fixed unit assembly automation as shown in figure 3 and figure 4. Similarly, if the fraction of the machine allocated cost is altered then this influences the magnitude as shown in the figure 3 which is a logistic growth curve. If a fraction of machines is perturbed from the base run case then no change in the behaviour pattern is found. The ease of the Average cost per station as shown in figure 4 which is also a logistic growth curve is similar. The yield remains the same which is very important and decisive factor in decision making. Figure 4 and figure 5 showing unit cost for fixed automation and multivariate simulation illustrates the variation in the intensity of the magnitude, while overall system behaviour remains the same. This also validates the model and allow us to consider what difference it can make if the unit assembly cost is managed by scenario of manual processes only.

5 Manual Assembly Scenario Study

This leads us to our 2nd case study model by Boothroyed, G. [15] for the manual assembly process as such its key attributes and key variable parameters are defined in Table 2 and as shown in the figures 6, 7, 8. Let us consider that the

Initial time 
\[ T_i = 0 \]

Final time 
\[ T_f = 420 \text{ Min} \]

Time Step: 
\[ dT = 0.25 \]

Any instant \( T \):
\[ T = \sum_{n=0}^{\infty} 0.25 \times n + T_i \] (3)

Where 
\[ n = \frac{T_f - T_i}{dT} \]

Let us consider the annual labour cost for assembly of the product can assumed as \( AL \) in terms of units of dollars per minutes thus at the initial time is given by as such: 
\[ AL = 1 \times 0.5 \]

Similarly, consider the annual production volume suppose \( Apr \), thus at the initial time in terms of product units/sec 
\[ Apr = 25 \]

Now consider the assembly time per part of the component of the product are taken at initial time in terms of minutes as such that 
\[ Pat = 3.6 \times \frac{1}{60} \]

Let us consider the number of hours per shift which are required for running shift in a year suppose at the initial time in terms of minutes of time as such

\[ Hshift = 2000 \times \frac{1}{60} \]

Let us assume that suppose there are significant number of the parts in a product at initial time in terms of units of the product are given by

\[ N_{part} = 10 \]

<table>
<thead>
<tr>
<th>Table (2) Variable Definition of Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable Name</strong></td>
</tr>
<tr>
<td>Annual Labour Cost</td>
</tr>
<tr>
<td>Annual Production Volume</td>
</tr>
<tr>
<td>Assembly time per part of the Component</td>
</tr>
<tr>
<td>Number of hours per shift</td>
</tr>
<tr>
<td>Production Yield</td>
</tr>
</tbody>
</table>
Similarly the percentage of the product passed and cleared by the quality and inspection consider that initial time in terms of the percents of units then as such:

\[ Q_{ins} = 99 \times 1/100 \]

Therefore yield rate can be considered at the initial time such as that at the initial time in terms of percents as it is cleared by the inspected and passed by the quality therefore,

\[ Yr = Q_{ins} \]

While total number of the people in terms of labour involved are considered as the number of people at initial time in terms of person as such

\[ N_{total} = N_{labor} \] .... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... (4)

Therefore now the \( N_{labor} \) at the final time \( T_f \) in terms of persons unit as such can be given as

\[
N_{labor}(T_f) = \int_{T_i}^{T_f} \left( Apr + Pat + HShift + N_{part/\text{product}} \right) \times dT + N_{labor}(T_i) \] .... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... (5)

Similarly Total number of people can be obtain from above equation (4) as such

\[
N_{Total}(T_f) = \int_{T_i}^{T_f} \left( Apr + Pat + HShift + N_{part/\text{product}} \right) \times dT + N_{Total}(T_i) \] .... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... (6)

Thus unit assembly cost by the manual assembly process can be taken as in final units of time as such that

\[
C_{Assembly\,Manual\,process}(T_f) = \int_{T_i}^{T_f} \left( Al + N_{total} \times \frac{1}{Apr} \times Yr \right) \times dT + C_{Assembly\,Manual\,process}(T_i) \] .... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... ... (7)

6. Results of the Case Study

It has been learned from the above model equations that if the number of the parts is decreased in the product then the less number of people will be needed to assemble as shown in results of figure 9. If the yield rate is decrease due to less people on the assembly line then this will significantly decreased the unit assembly cost by manual assembly process due to less number of people as shown in the figure 10 this reflects the fact that the number of people has great influence assembly lines, in case of manual assembly, will make the difference to achieve 95% as shown in the figure 11.

7. Discussion & Analysis of Case Studies

The result shows us explicitly the fact that manual assembly, in case of quick change over and over will need to keep abreast with the ramp-up processes during the assembly of the product. As if the parts increases due to variety then so as the complexity [16] which will in turn affect the quality of the assembly process. Therefore, for low batch with low variety the labour force is contended as well as the capital cost per product. On the other hand when we have the medium variety and large batches of production volume which can be split into middle batches of fixed automation. But with passage of time wear and tear occurs in machines thus deteriorating fixed automated machines down time which can result in low volume assembly yield. Similarly, every now and then changes in design features affect soft and hard enablers configurations because of market pull which is needed to be accommodated. For large variety with customization and personalization along with mass production, then the fixed assembly line does not support the fast and effective ramp-up
needed to provide agile response to the market. In case of the manual assembly, change was accommodated in assembly system because of the dexterity among humans where as we Homo sapiens are mentally adroit and skilful; although different from one another but we can easily adapt to new tasks when the assembly line requires convertibility or change and scalability. If the market growth is sluggish the production system is scaled down and hence there are fewer people on the line. However, the system becomes scaled down automatically if the product variety becomes quite high as is the case for assembly systems like automobiles where assembly is highly complex, compared to packing of fruits, vegetables, donuts, cookies and candies. In manual assembly systems the complexity due to mass customization and personalization may cause human errors, which in turn impact the quality of the product. Therefore, manual assembly has a limitation on high number of product variety or production mix. Thus, due to fluctuation in market and increasing product variety and production mix in order to achieve scalability as and when desired the fixed assembly automation also has the limitation. Therefore, reconfigurable manufacturing system meet the challenges of the fast and effective production ramp up which enables the system to accommodate any change required when needed due to short life cycle of the products and market demands. Hence, it meets all requirement of the computer integrated manufacturing (CIM) by means of latest state of the art technological upgrades in hard and soft enablers. Furthermore, the Extrinsic variable of number of people distribution projects a goal seek behaviour as the negative exponential growth is observed as the system evolution progresses with time. The distribution projects the same goal seek behaviour as the Monte Carlo sensitivity analysis runs completed. However, the system evolution shows saturation of the projection owing to its upper and lower bound of random variable limit with negative exponential growth in the beginning of the unit of the time for both of the dependent level variables of the system.

8. Conclusions

Effective and fast production ramp-Up is now a growing problem which challenges the industry often in order to keep the competitive edge in the market. This paper contributes by means of simple system dynamic models that justify the fact that fast and effective production ramp-Up planning is achievable through reconfigurable manufacturing. The results of case studies conclude that if lesser number of people are employed then overall cost of assembly will be less in terms of labour cost. But if more people are employed and also more parts are there to assemble then cost factor will increase significantly, which is not surprising. Obviously, it is very likely that human errors can impact the quality of the product with the increase in parts and variety. Therefore, manual assembly has a limitation on number of product variety in case of production mix. Next, in case of fixed automation medium variety can be accommodated as long as the multipurpose functionality of the similar machine tools allows, but not very high volume and high variety. As we see the mass production system suits well to dedicated production line where there is low variety in design and fabrication process. Moreover, increasing product variety due to mass customization and personalization causes production mix and in order to achieve the scalability, as and when desired due to fluctuation of the market, only reconfigurable machining system is considered as the best choice. Therefore, reconfigurable manufacturing system is strongly preferred and recommended. Hence the justification is logical also owing to the fact of never ending ramp-up scenario which have emerged due to continuous evolution in products features and as well as in variety that is necessary to meet the diverse market demands.

REFERENCES