

USABILITY OF RECONFIGURABLE MANUFACTURING SYSTEMS

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Abstract

Reconfigurable manufacturing systems (RMS) are systems that are designed for cost effective response to changes in production requirements. Well-designed RMS are those systems able to cope with random changes in production requirements. Reconfiguration is an iterative process that entails setting of the system configuration that is optimally fit for various purposes. Although RMS are considered to be highly automated systems, still there is a human involvement in the process of reconfiguration itself. This enforces considering the human as the user of the RMS equipment on both physical and cognitive levels. Also, it is presumed that a highly usable manufacturing system will guarantee rapid system's reconfigurability to be able to acquire high rate of customized output. This research investigates the level at which usability is contributing to the flexibility and dynamic changeability of a reconfigurable manufacturing system. It addresses the equipment reconfigurability, usability, along with different environmental working conditions e.g. physical work environment, organizational conditions, and task characteristics. The evaluation of these attributes was done via constructing single utility function for each attribute. Multi-attribute utility analysis (MAUA) was used to integrate these utility functions in a single utility function which includes weight for reconfigurability, usability, and conditions. To compute these weights and estimate the level of usability importance in the reconfiguration process, weights are estimated through the implementation of the suggested function on a selected case study.

Keywords

Reconfigurable Manufacturing Systems, Usability Evaluation, Utility Function.

1 Introduction

The ability to handle changes and quickly manage manufacturing and the manufacturing system to compensate for external demands is becoming an important competitive factor. Success in manufacturing and within the production system is increasingly more difficult to ensure and demands continuous development and improvement. Meeting customer demands requires a high degree of flexibility as well as abilities to reconfigure operations for new demands. As a result, the performance of how the products are developed within the system will be a strategic weapon for competition in a turbulent business environment. The performance of the manufacturing system is largely dependent on the ability to be flexible as well as being able to reconfigure operations for new demands. As explained by (Malhotra V, 2009) the four types of manufacturing systems are 1) Classic Machining Systems, 2) Dedicated Manufacturing Systems, 3) Flexible Manufacturing Systems, and 4) Reconfigurable Manufacturing Systems. RMS systems are created by basic modules arranged efficiently and effectively. Its objective is to provide exactly the functionality and capacity exactly when needed.

1.1 Reconfiguration Process

The system configuration of reconfigurable manufacturing systems can be similar to dedicated or flexible systems, or a combination of both. While RMS may lie between DMS and FMS in terms of capacity and functionality, this is not its distinguishing feature. The key feature of RMS is that, unlike DMSs and FMSs, its capacity and functionality are not fixed (Mehrabi MG, 2000). (Koren Y, 1999) proved that reconfigurable systems must be designed at the outset to be reconfigurable, and must be

created by using hardware and software modules that can be integrated quickly and reliably; otherwise, the reconfiguration process will be both lengthy and impractical. Achieving this design goal requires a RMS that possesses the key characteristics as in (ElMaraghy, 2006) that are 1) Modularity, 2) Integrability, 3) Customization, 4) Convertibility, and 5) Diagnosability. But (Malhotra V, 2009) explained that there are unique features of RMS that are: 1) Dynamic Behavior, 2) Integrated Information, 3) Oriented Innovation, 4) Environment Consciousness and 5) Competition and Cooperation. Even with modular design platforms companies need to tailor their production lines to match the rapid response to market changes and consumer needs. Meeting customer demands requires a high degree of flexibility as well as ability to reconfigure operations for changeable demands, new product designs, and technologies. Reconfigurable Systems are focusing on responsiveness, and achieving it at a low cost and rapid time. Although an RMS is a highly automated system, yet it is believed that the goals of RMS cannot be achieved successfully without a special attention to the inevitable human involvement in the reconfiguration process. This process involves human/machine interaction on both physical and cognitive levels.

1.2 Usability of RMS

Usability was probably first described by (Miller, 1971) in terms of measures for “ease of use”, and these were developed further by (Bennett, 1979) to describe usability. The concept of usability was first fully discussed and a detailed formal definition, as above, was attempted by (Shackel, 1981), and (Bennett, 1984). The problem with these definitions is that they are conceptually satisfactory but still only generalized in form; they do not specify what usability is in quantifiable or measurable terms.

Despite the increasing attention usability has received over the years, it is often discussed as a user interface matter alone, or a matter of applying simple design guidelines (Boivie, 2006). Lately, researchers started considering the impact of usability on the entire system (Chao-Hsien Lin, 2009). While others investigated impact of the human performance on the RMS like (W. H. Elmaraghy, 2008). In this research the impact of both usability and reconfigurability on the manufacturing system and its effect on the human performance is evaluated. Rapidly changing demands of products with short life cycles requires the manufacturing systems to be carefully designed and planned to cope with the multiple products and the increasing number of product variants.

2 Model Development

A model is developed to address the parameters affecting the changeover process in a reconfigurable manufacturing system. The objective of the model is to evaluate the usability influence on the utility of a reconfigurable manufacturing system. The procedure considered for investigating the changeover of the RMS systems owing to different system characteristics that may influence the operators' performance. The level of systems' reconfigurability, usability of machine parts, and equipment; the interaction between the workers / machine and working environment during the reconfiguration process are the focus of this study. Cause and effect analysis is used to classify quality factors that affect directly the reconfiguration process. Next, is to identify the sets of attributes that contribute to the human performance and then adopt the multi-attribute utility theory (Keeney, 1976) to develop a measure for human performance based on those sets of attributes. The procedure includes both qualitative and quantitative analysis. Each utility function is conceived based on experience and subjective determination of the shape of the utility function, followed by quantitative assessment and verification of limit values. The shape of these functions is not unique, and it is possible to achieve close quantitative results using other utility function shapes. Operator's personal capabilities such as motivation, experience, and culture may also be included in the proposed predictive model, using the same procedure outlined in the present paper. Any available quantitative data for actual systems can also be used to further fine-tune the shape of the utility functions. The first step in applying the multi-attribute theory is to develop utility functions to represent the utility of single attributes. A utility function is capable of translating the value of an attribute into 'utility units'. A utility function $u(x_i)$ serves to assess the effects of the magnitudes of the x_i attribute on the utility

$u(x_i)$. In this research, information from literature is used in the development of the individual utility functions. Questionnaires filled by the operators, engineers and senior managers together with individual decision making were both used in the determination of the trends and the weights of the utility functions.

2.1 Reconfigurability Set of Attributes

In order to derive analytically the contribution of each attribute to human performance during the changeover process, we should first define:

X: set of attributes representing the reconfigurability; $X = \{x_1, x_2\}$

- X_1 : an attribute representing the universality of equipment.
 - X_2 : an attribute representing the modularity of the machine.
- $U_x(x_i)$: reconfiguration utility for the attribute x_i , $i = 1, 2$.

2.1.1 Universality of Equipment

Assessing the level of universality of equipment (x_1) is based on the number of tasks a single piece of equipment can perform. It can be calculated using equation (1):

$$x_1 = \frac{N_c}{N_t} \quad (1) \quad \text{Where} \quad N_c: \text{number of task performed.}$$

N_t : number of tools used

Its utility function can be expressed by equation (2)

$$U_x(x_1) = 0.1 X_1 \quad (2)$$

2.1.2 Modularity of Machine

Assessing the level of Modularity (x_2) is based on the number of machine parts contributing in the reconfiguration process. It can be calculated using equation (3):

$$x_2 = \frac{N_m}{N_p} \quad (3) \quad \text{Where} \quad N_m: \text{number of modules}$$

N_p : number of machine parts contributing in reconfiguration

Its utility function can be expressed by equation (4)

$$U_x(x_2) = 0.1 X_2 \quad (4)$$

2.2 Usability Set of Attributes

It was claimed that usability affects the manufacturing system reconfigurability and, hence, it also affects the human performance during the changeover process. In order to analytically derive the contribution of each attribute to the human performance, we should first define:

Y: set of attributes representing usability of the manufacturing system; $y = \{y_1, y_2, y_3, y_4\}$

- Y_1 : an attribute representing the visibility of the labels.
- Y_2 : an attribute representing affordance of the machine parts the worker interacts with.
- Y_3 : an attribute representing physical constraints of the machine parts.
- Y_4 : an attribute representing consistency.

$U_y(Y_i)$: usability utility for the attribute Y_i , $i = 1, 2, 3, 4$.

2.2.1 Visibility of the labels

The relevant parts should be visible where the user by looking should be able to tell the state of the device and the alternatives for action (Norman, 1988). The level of visibility may be assessed by a subjective score ranges between 0 and 10. Its utility function can be calculated by equation (5):

$$U_Y(y_1) = 0.088 Y_1^{1.05} \quad (5)$$

2.2.2 Affordance

Similar to visibility, the level of affordance is assessed by score range between 0 and 10.

Its utility function can be expressed by equation (6): $U_y(y_2) = 0.088 Y_2^{1.05} \quad (6)$

2.2.3 Physical Constraints

Physical constraint (Y_3) is to constrain possible actions like cars that cannot start unless in park or neutral. It can be estimated by equation (7):

$$y_2 = \frac{N_{pc}}{N_{tp}} \quad (7) \quad \text{Where } N_{pc}: \text{Number of existing physical constraints.}$$

N_{tp} : total number of necessary physical constraints.

Its utility function can be expressed by equation (8): $U_y(Y_3) = 0.0183 e^{0.3994 y_3}$ (8)

2.2.4 Consistency

The level of consistency may be assessed by a subjective score ranges between 0 -10 based on the results of a questionnaire that have been asked to seven workers. Its utility function may be expressed by equation (9): $U_y(Y_4) = 0.18 Y_4^{0.744}$ (9)

2.3 Working Environment

Work environment characteristics as well as system's operating characteristics that could affect the human performance are captured through the set of attributes Z . Let us define:

Z : set of attributes representing the working environment $Z = \{Z_1, Z_2\}$

- Z_1 : an attribute representing the physical work environment
- Z_2 : an attribute representing the difficulty of task.

$U_z(Z_i)$: Work environment characteristics. Utility for the attribute Z_i , $i = 1, 2$.

2.3.1 The physical working environment

An attribute is used to represent the physical work environment such as ergonomic design of workplace, lightening, temperature and noise. The empirical verification of the existence of a positive relationship between the ergonomic design of workplaces and achieved product quality levels has been addressed in several publications (Helander, 1994), (Eklund, 1995), (Schwind, 1996), (Gonzalez, 2003), (Shikdar, 2003). In the current study, the attribute Z_1 will account for assessing 'how good is the physical work environment'.

$$Z_1 = \frac{\sum_{j=1}^{M_c} E_j}{N_w} \quad (10) \quad \text{Where } E_j: \text{physical working environment for each worker.}$$

N_w : number of worker asked.

Its utility is calculated in equation (11): $U_z(Z_1) = e^{-0.4Z_1}$ (11)

2.3.2 Difficulty of Task

The difficulty of physical task elements Z_4 can be calculated as using equation (12).

$$Z_2 = \frac{\sum_{k=1}^{M_p} D_{pk}}{M_p} \quad (12) \quad \text{Where } M_p: \text{number of physical task elements.}$$

D_{pk} : inherent difficulty of physical task element k

The utility function for the difficulty of physical task elements have been constructed to be monotonically increasing as the difficulty increases and can be expressed by equation (13)

$U_z(Z_2) = 0.0189 Z_2^{0.3972}$ (13). Upon the scores collected from the interviews with the operators.

3 Model Implementation: Reconfiguration Steps

The proposed model was experimented at Unilever Egypt Group. A detailed survey was carried out on the working team of seven operators for a machine that produces twelve different food powder products. The reconfiguration steps are as follows: 1) Installing suitable Roll Panel, 2) adjusting vertical and horizontal guides 3) Photocell check, 4) setting date stamp, 5) Resizing grabbing arms and scissors, 6) Modifying the mechanism responsible of transferring the packet throughout the process, and 7) Installing the suitable Release Nozzle.

4 The impact of different parameters on the overall utility function

In order to investigate the effect of different attributes on the overall utility, various scenarios were considered. Figure 2 illustrates the effect of varying visibility of labels as well as the difficulty of task Vs. the overall utility. It depicts the combined effect of the utility curves of the two attributes. Such a curve can be useful when the system designer is faced with a scenario in which changes in the product design will result in an increase in the difficulty of task. Assuming that the designer is satisfied with the current level of worker performance, in this case the designer can use such a figure to compensate for the difficulty increase through the adjustment of the visibility of labels to achieve the same level for the overall utility. This can also be achieved through enhancing the reconfigurability design for the machine with better modularity features of the machine parts. Similar three-dimensional plots can be used to demonstrate the impact of varying two different attributes on the overall utility. For instance, figure 3 illustrates the relation between the difficulty of tasks as well as the modularity of the machine impact the overall utility. It indicates highest performance is achieved at the highest value for the modularity and lowest value for the task difficulty. The obtained results indicate that the developed model is capable of capturing the different attributes contributing to human performance. The model can help the designer in investigating different scenarios and assessing different alternatives for maximizing the benefit from the human involvement. These alternatives may include changing the task design to minimize its difficulty, increasing the visibility of the labels, and enhancing the work environment. The use of such proactive assessment tool is more critical in the context of reconfigurable manufacturing systems because frequent operators' task reallocation is expected due to the system reconfiguration. It was assumed that the total utility function of the machine is computed by the equation: Total utility = $U(x) * W_x + U(y) * W_y + U(z) * W_z$; where W_x , W_y , and W_z , refer to weight of reconfiguration, weight of usability, and weight of working environment respectively.

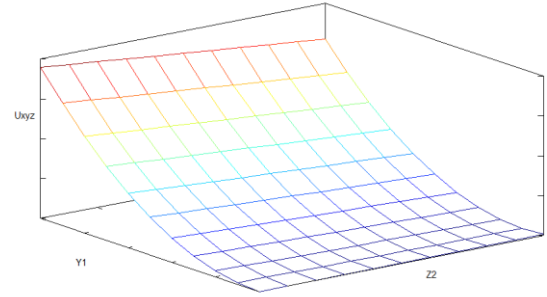


Figure 2 Relation Between (Uxyz, Y1, Z2)

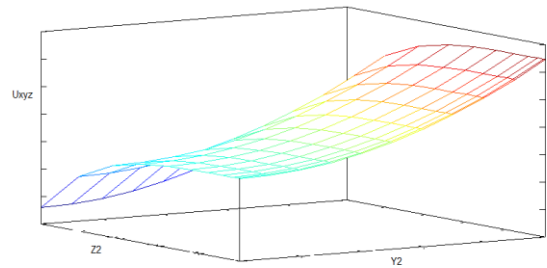


Figure 1 Relation between (Uxyz, Z2, Y2)

5 Results and Discussion

In the considered application of the model, the values for human performance attributes provided in the previous section were used to assess the overall utility. This was accomplished after generating the equation of utility function of each parameter. Utility function equations for reconfigurability, usability and working environment are: $U(x) = 0.032x_1 + 0.068x_2$

$$U(y) = 0.023y_1 + 0.03y_2^{1.05} + 1.46 * 10^{-3}e^{-0.3994y_3} + 0.03y_4^{1.05}$$

$$U(z) = 0.29e^{-0.4z_1} + 4.7 * 10^{-3}z_2^{0.397}$$

In this model, it is reasonably assumed that the three machines have different values of utility. The other values for attributes concerning the usability, reconfigurability and work environment are assigned their values with the Analysis Hierarchy Process (AHP) method. Elmaraghy (2008) has defined a standard method that has been used in assessing the weights for the attributes. The calculated weights for reconfigurability are: $W_{x1} = 0.32$, $W_{x2} = 0.68$. For usability are: $W_{y1} = 0.23$, $W_{y2} = 0.35$, $W_{y3} = 0.08$, $W_{y4} = 0.34$. And for working environment are as follows: $W_{z1} = 0.41$, $W_{z2} = 0.59$. The total weights values W_x , W_y , and W_z are 0.421, 0.436, and 0.143 respectively. Knowing that $W_x + W_y + W_z = 1$ The resulting utilities for the machine are as follows: $U(x) = 0.32$, $U(y) = 0.63$, $U(z) = 0.05$. The total utility function equation would result to be $U_t = 0.32w_x + 0.63w_y + 0.05w_z$

6 Conclusion

A model using multi attribute utility analysis was developed to estimate the level of influence of selected RMS characteristics on the responsiveness and the quick time of reconfiguration process. The suggested model addresses three main characteristics that is believed to have a high impact on the human/ machine interaction during the reconfiguration process, these characteristics are Reconfigurability, Usability of the machine and the working environment including, physical environmental conditions, task characteristics along with organizational aspects. Root cause analysis was used to find the root attributes that affect the reconfiguration process. The suggested model assigns a weight for each addressed RMS characteristic, so it can give an indication of the most important characteristic that could be considered in the systems design to improve the systems conformance to high responsiveness. This work introduces an approach to examine the importance of usability of a manufacturing system, especially when high dynamic changes are involved, such as those in RMSs. Multi Attribute Utility theory was used to derive each characteristic's weight contributing in the overall utility of the manufacturing system. The weight of usability is calculated after implementing the derived function. The calculated weight implies that the usability principles have the same importance as the reconfigurability ones in the design of a reconfigurable manufacturing system.

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