RESPONSIVENESS MEASUREMENT OF RECONFIGURABLE MANUFACTURING SYSTEM

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Abstract: *Reconfigurable manufacturing systems (RMS) are considered as manufacturing systems that are capable of providing the exact functionality and capacity as and when desired. Volatility of demand, requirement of variety of products, quick development in product and process technology has forced the manufacturing systems to become accustomed the changing requirements efficiently. There are various performance measures like ramp-up time, cost, reliability, availability, lead time, reconfiguration time etc. that affects performance of the reconfiguration manufacturing system. This chapter focuses on the performance measures like reconfiguration time, reconfiguration reliability and the way to find the responsiveness of reconfigurable manufacturing system.*

Key words: *Reconfigurable manufacturing systems, reconfiguration time, reliability, responsiveness, performance measures*

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1. Introduction

In the manufacturing industry, some of the challenges faced by manufacturers include reducing the lead time, increasing the quality, providing variety of products. Although dedicated manufacturing lines (DMLs) the traditional manufacturing system are capable of producing the similar products in bulk but are incapable of accommodating the product variety. On the other side, Flexible manufacturing system (FMSs) are capable of accommodating the product variety but in comparison to DML the productivity is low (Mehrabi & Ulsoy,2000; Katalinic et al.,2012). Besides that the cost of FMSs are very high and therefore have very limited acceptability among the manufacturers (Gupta et al.,2012;Mehrabi et al.,2002; Mittal & Jain,2014). Reconfigurable manufacturing systems (RMS) a new type of manufacturing system has the capability to adjust both capacity and functionality in order to cope up with product variety and production volume (Chao et al., 2010, ElMaraghy, 2006a; Goyal et al., 2012). The overall vision of reconfigurable manufacturing systems (RMSs), as systems of equipment, having a modular structure, that have customized flexibility so one can easily reconfigure the entire system to produce a family of products at different production volumes. Koren & Ulsoy,(1997); Koren,(2013) was the first to describe how the system configuration has a significant impact on the performance of the RMS in terms of throughput and quality. Koren & Ulsoy,(1997); Koren,(2013) described the effects of system configurations for RMS sand concluded that parallel configurations with cross-over yield significant benefits in throughput, performance and scalability when identical machines are used throughout the system. Other publications such as (ElMaraghy,2006b; Alejandro et al.,2013) discuss various method of making capacity decisions for reconfigurable manufacturing systems taking into account issues such as equipment selection, multipart production, and stochastic demand. However, little focus has been given on the modularity of Reconfigurable Machine Tool (RMT). RMS having its core component Reconfigurable Machine Tool (RMT).The Reconfigurable Machine Tools are developed as modular machines having different modules (Koren,1999; Koren,2005; Galan et al.,2007;Goyal et al.,2011).The RMTs having basic and auxiliary modules. The basic modules are such as base, slide ways and auxiliary modules are such as spindle heads, tool changer which are relatively smaller and lighter than the basic modules. The auxiliary module can be quickly and easily changed with minimum effort. By adding or removing the RMTs can be reconfigured into many other configurations (Koren et al.1998; Youssef& ElMaraghy,2006; Youssef& ElMaraghy,2007; Goyal et al.,2011). Figure 1 shows the configuration of RMTs from the standard module library, in which two machine configurations of a machine are assembled by just varying the auxiliary modules. The detailed analysis of module interactions at the machine level has not been considered in most of the RMS models, which is the key enabler of responsiveness of RMS.Because of this, importance of the present study is on the development of responsiveness measure at the machine level which would definitely reduce the reconfiguration efforts required at various levels in the later stage.

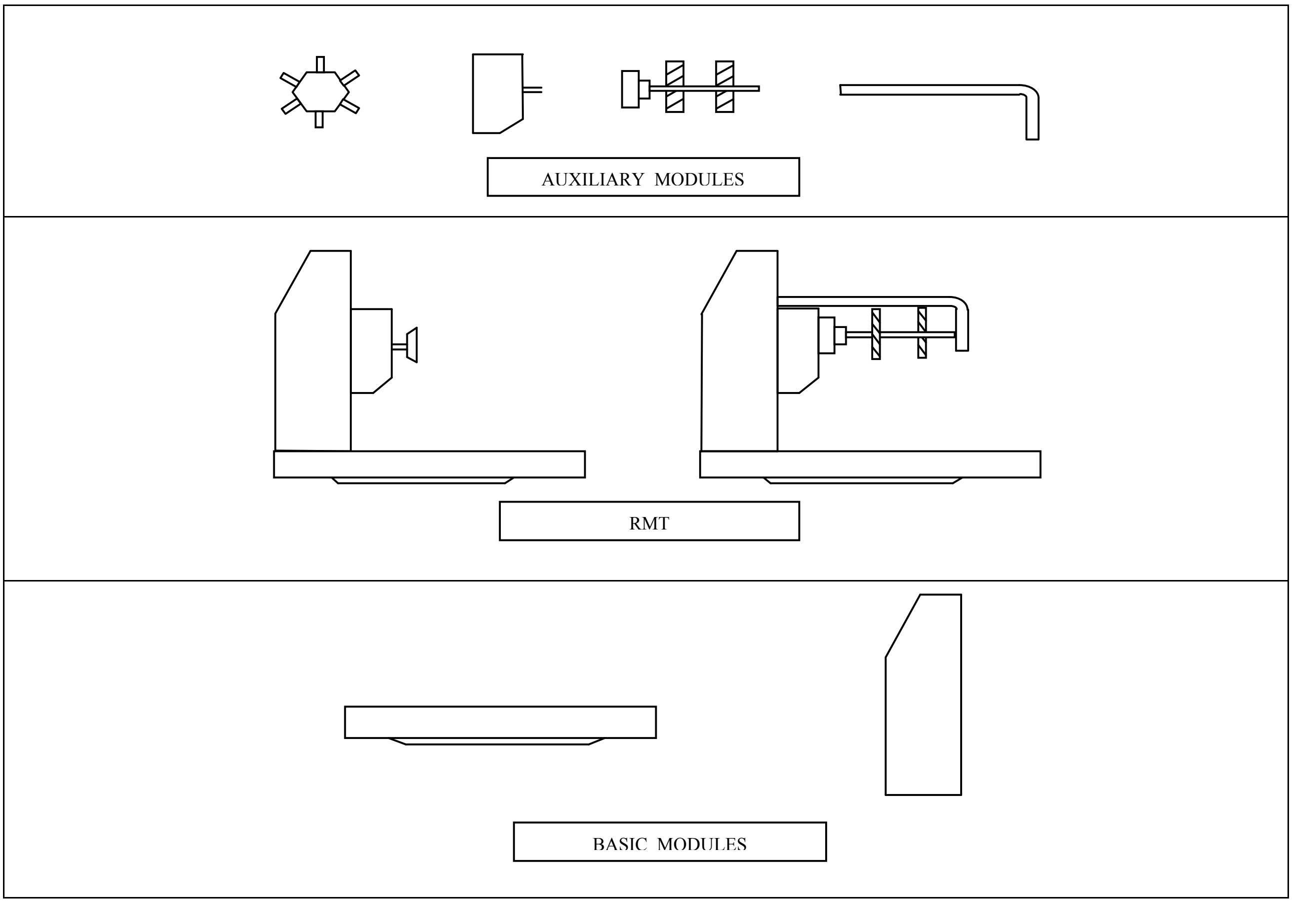


Fig. 1. RMT's configurations from standard module library

2. Requisite of the performance measure

Reconfiguring the system components over the time for a diverse set of individualized products often required in small quantities and with very short delivery lead time. This necessitates the requirement of mapping the manufacturing system capabilities and other characteristics by developing a suitable performance measure. To measure the performance of RMS, their various core characteristics such as modularity, scalability, convertibility and diagnosability should be considered (Gumasta,2011; Mittal & Jain,2014). In most of the RMS modeling, the reduction in cost and reconfiguration effort is considered an objective. Many researchers have addressed the problem in two phases. In the first phase, solutions are recorded for each stage based on cost as a criterion. In the subsequent stage, the best alternatives are chosen from the previously recorded alternatives for each time horizon based on the objective to minimize the reconfigurations required at various stages (ElMaraghy& Deif 2006; Goyal et al.,2012). A new manufacturing paradigm, called Reconfigurable Manufacturing Systems (RMSs) is designed for rapid adjustment of production capacity and functionality, in response to new circumstances, by rearrangement or change of its components. These new systems provide exactly the functionality that is needed, exactly when it is needed (Mehrabi & Ulsoy,2000). Therefore, a RMS is designed to be easily reconfigured such that it is able to process a family of parts and accommodate new and unanticipated changes in the product design and processing needs. The utility of a RMS is greatly increased if it is highly responsive in nature.The responsiveness is dependent on various performance measures like reconfiguration time and reconfiguration reliability. The measurement of responsiveness can be calculated by calculating reconfiguration time, reconfiguration reliability etc. The benefits of configurability include economies of scale, increased feasibility of product / component change, increased product variety, and reduced lead time (Yigit & Allahverdi,2003).

3. Reconfiguration time

Reconfiguration time is the time taken in changing one configuration to another configuration. The time includes adding, removing and readjusting the modules. Tab. 1 gives different machine configurations with their basic and auxiliary modules.

Machine configurations	Basic Module(BM)	Auxiliary Modules(AM)
mc_1^1	(a,b)	(c,d,e)
mc_1^2	(a,b)	(e,g,h)
mc_1^3	(a,b)	(c,d,g,f)

Tab. 1. Basic and Auxiliary module for different machine configurations

Tab. 2 gives the reconfiguration time in adding the auxiliary module from one configuration to another.

Module \ Reconfiguration time	12	23	31	21	32	13
c	-	1	-	1	-	-
d	-	3	-	1	-	-
e	-	-	4		2	-
f	-	4	-	-	-	4
g	6	-	-	-	-	4
h	6	-	-	-	6	-

Tab. 2. Reconfiguration time (sec) when adding the Auxiliary module

NRAT (Normalized Reconfiguration addition time) for different auxiliary module is given by

$$NRAT = \alpha\, mc_{ij} + \beta\, mc_{pq} \tag{1}$$

where α & β are the weights assigned ($\alpha + \beta=1$) and i, j, p, q=1, 2, 3 and the assumed value of α & β are 0.5.E.g. for auxiliary module c, $NRAT_c= \alpha\, mc_{23} + \beta\, mc_{21} = (1+1)/2=1$

Similarly Normalized Reconfiguration addition time for different auxiliary modules can be calculated and listed in Tab. 5.

Tab. 3 gives the reconfiguration time in removing the auxiliary module from one configuration to another.

Module \ Reconfiguration time	12	23	31	21	32	13
c	.5	-	-	-	.5	-
d	1	-	-	-	1	-
e	-	2	-	-	-	1
f	-	-	1	-	3	-
g	-	-	2	3	-	-
h	-	4	-	2	-	-

Tab. 3. Reconfiguration time (sec) when removing the Auxiliary module

NRRT (Normalized Reconfiguration removal time) for different auxiliary module is given by

$$NRRT= \boldsymbol{\sigma}\ mc_{ij} +\Omega\ mc_{pq} \quad (2)$$

where $\boldsymbol{\sigma}$ & Ω are the weights assigned ($\boldsymbol{\sigma} + \Omega = 1$) and i, j, p, q=1, 2, 3 and the assumed value of $\boldsymbol{\sigma}$ & Ω are 0.5.E.g. for auxiliary module c, $NRRT_c = \boldsymbol{\sigma}\ mc_{12} + \Omega\ mc_{32} = 0.5$

Similarly Normalized Reconfiguration removal time for different auxiliary modules can be calculated and listed in Tab. 5.

Tab. 4 gives the reconfiguration time in readjusting the auxiliary module from one configuration to another.

Module \ Rec. time	12	23	31	21	32	13
c	-	-	0.8	-	-	0.6
d	-	-	1.2	-	-	1.8
e	2.5	-	-	1.5	-	-
f	-	-	-	-	-	-
g	-	2	-	-	2	-
h	-	-	-	-	-	-

Tab. 4. Reconfiguration time (sec) when readjusting the Auxiliary module

NRReT (Normalized Reconfiguration readjustment time) for different auxiliary module is given by

$$NRReT = \mu\ mc_{ij} +\partial\ mc_{pq} \quad (3)$$

where μ & Ω are the weights assigned ($\mu + \partial = 1$) and i, j, p, q=1, 2, 3 and the assumed value of μ & ∂ are 0.5.E.g. for auxiliary module c, $NRReT_c = \mu\ mc_{12} + \partial\ mc_{32} = 0.7$

Similarly Normalized Reconfiguration readjustment time for different auxiliary modules can be calculated and listed in Tab. 5.

Tab. 5 gives the normalized value of reconfiguration time in adding, removing and readjusting the auxiliary module from one configuration to another.

Auxiliary Modules	Reconfiguration time when adding the module	Reconfiguration time when removing the module	Reconfiguration time when readjusting the module
c	1	.5	.7
d	2	1	1.5
e	3	1.5	2
f	4	2	-
g	5	2.5	4
h	6	3	-

Tab. 5. Reconfiguration time (sec) for different Auxiliary module (Normalized value)

Total Reconfiguration Time(TRT) can be calculated as follows

$$TRT_{ij} = \left(\mu \frac{\text{time in adding the module}}{\text{Total available time}} + \Omega \frac{\text{time in removing the module}}{\text{Total available time}} + \sigma \frac{\text{time in readjusting the module}}{\text{Total available time}}\right) \quad (4)$$

where i, j=1, 2, 3;and the assumed value of different weights are $\mu = .5$, $\Omega = .4$, σ=.1 and Total available time =20 sec

The modules added are g and h, the modules removed are c and d and the modules readjusted are e in changing configuration 1 to 2.Hence Total Reconfiguration Time(TRT_{12})=.5(5+6)/20 + .4(1.5)/20 + .1(2)/20 = .315

Similarly Total Reconfiguration Time for TRT_{13}, TRT_{23}, TRT_{32}, TRT_{31} and TRT_{21} can be calculated and listed in Tab. 6.

S.No.	Total Reconfiguration Time	Results
1.	TRT_{12}	0.315
2.	TRT_{13}	0.266
3.	TRT_{23}	0.285
4.	TRT_{32}	0.315
5.	TRT_{31}	0.176
6.	TRT_{21}	0.195

Tab. 6. Total Reconfiguration time

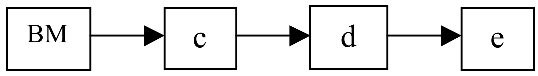
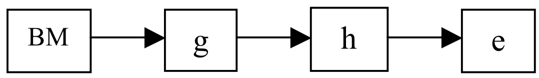
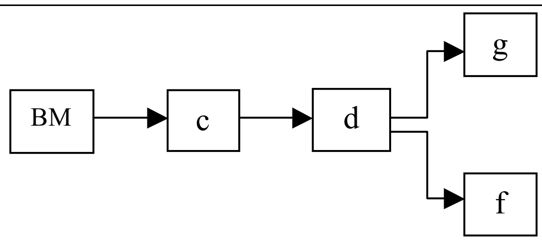
4. Reconfiguration reliability

Reconfiguration reliability is the reliability in changing one configuration to another configuration. The reliability includes adding, removing and readjusting the modules. Tab. 7 gives reliability of basic and auxiliary modules.

Modules	Reliability(R)
Basic Module(BM)	.9
c	.9
d	.8
e	.7
f	.6
g	.7
h	.6

Tab. 7. Reliability for different modules

The machine configurations and their structure is given in Tab. 8.

Machine configurations	Structure of modules
mc_1^1	
mc_1^2	
mc_1^3	

Tab. 8. Structure of modules

Reconfiguration Reliability (RR) for different changeover is calulated as below.

$$(RR)_{ij} = R_p x.....x R_q \qquad (5)$$

where $_{i,j}$=1, 2, 3 and p,q=BM,c,d,g,h,e,f if the moduleds are in series.

$$(RR)_{ij} = [1-(1-R_p)x......x(1-R_q)] \qquad (6)$$

where $_{i,\,j}$=1, 2, 3 and p,q=BM,c,d,g,h,e,f if the moduleds are in parallel.

e.g The Reconfiguration Reliability (RR_{12}) can be calculated as below

RR_{12}= .9 x .7 x .6 x .7 = .2646

The Reconfiguration Reliability for different changeover is listed in the Tab. 9.

S.No.	Reconfiguration Reliability	Results
1.	RR_{12}	0.2646
2.	RR_{13}	0.5702
3.	RR_{23}	0.5702
4.	RR_{32}	0.2646
5.	RR_{31}	0.4536
6.	RR_{21}	0.4536

Tab. 9. Reconfiguration Reliability

5. Reconfigurable responsiveness index

Both the performance measures discussed above directly influ-ence theresponsiveness of the RMS. Therefore the Reconfiguration Reliability and Reconfiguration time should be combined together to achive the responsiveness of the RMS.The Reconfigurable Responsiveness Index (RRI) is calculated as follows:

$$(RRI)_{stage} = \sigma\,(RR) + \lambda\,(RT) \qquad (7)$$

where,σ = .8 and λ =.2 , where $\sigma + \lambda = 1$.

Since the reliability should be higher than reconfiguration time ,hence the values of σ is higher than λ.

e.g The Reconfigurable Responsiveness Index $(RRI)_{stage}$ can be calculated as below in changing one configuration to another.

RRI_{12} = .8x RR_{12}+ .2xTRT_{12} = .8x0 .2646+ .2x.315 =.2746

The Reconfigurable Responsiveness Index for different changeover is listed in the Tab. 10.

S.No.	Reconfigurable Responsiveness Index	Results
1.	RRI_{12}	0.2746
2.	RRI_{13}	0.5093
3.	RRI_{23}	0.5131
4.	RRI_{32}	0.2746
5.	RRI_{31}	0.3980
6.	RRI_{21}	0.4018

Tab. 10. Reconfigurable Responsiveness Index

The Reconfigurable Responsiveness Index is given as below
$(RRI)_{stage} = (RRI_{12} + \ldots\ldots\ldots\ldots\ldots\ldots + RRI_{21}) / 6 = 0.3952$, considering equal importance at each changeover.

Similarly RRI for all stages and RRI for the system can be computed.

6. Conclusion

The present work, propose performance measures enabling responsive reconfigurable manufacturing system, shop floor operations. On the shop floor we plan to improve responsiveness on a set of RMT (Reconfigurable Machine Tools). This would enable the system to adjust functionality and capacity according to feedback from demand and market fluctuations. The performance measures of the Reconfigurable manufacturing system gives an indication to choose the configuration in each stage. In the present study the performance parameter reconfiguration time and reconfiguration reliability have been discussed. These performance parameters are helpful in measurment of responsiveness of RMS. In future the authors plan to develop more performance parameter to the manufacturing system. This research gives a baseline for future research on quantifying responsiveness and therefore reconfigurability of reconfigurable manufacturing systems. There are many ways to extend this work in the future. Effects of material handling devices, tools, fixtures, etc. can also be considered in the process of finding the reconfigurability of the system. Furthermore, work can be done on calculating the responsiveness of the entire system.

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