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Performance Analysis of a Virtual Cellular Manufacturing Flow-shop

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Abstract—*Research in the area of virtual cellular manufacturing (VCM) systems has gained momentum in the past decade. In practice, VCM systems offer the potential to harness the benefits of both cellular manufacturing (CM) and traditional manufacturing systems with a functional layout (FL). This paper considers the problem of family oriented VCM scheduling to enable setup efficiencies within a functionally organized manufacturing flow-shop. The goal is to develop and test a novel VCM concept that directly addresses these operational issues and highlights the advantages of the suggested technique through a discrete event simulation model of a hypothetical manufacturing situation.*

1. INTRODUCTION

The manufacturing sector has become increasingly competitive as markets become more globalized. As a result producers of goods are under constant and intense pressure to quickly and continuously improve their operations by enhancing productivity, quality and customer responsiveness. Driven by the need to reduce the manufacturing costs, there has been a major shift in the design of manufacturing systems using innovative concepts. The adoption of cellular manufacturing (CM) forms a central element for many of these efforts and has received considerable interest from both practitioners and academicians. Cellular layouts (CL) provide important benefits (Shafer and Charnes 1997) such as: operations overlapping, setup time reduction, reduction in move times, and the simultaneous setup of all equipment in a cell. The efforts required to set-up the machine is reduced since each cell process similar parts.

2. LITERATURE REVIEW

Flynn (1987) compared the effect of the repetitive lots sequencing procedure of Jacobs and Bragg (1988) in a functional and a cellular layout, as well as a functional layout with dedicated equipment. The Suresh's (1991, 1992) queuing theory-based models showed that these results are primarily due to the loss of routing flexibility when job shop work centers are partitioned when converting to cellular layout. Kannan and Ghosh (1996a) explored the performance measures of functional, cellular and two virtual manufacturing cell (VMC) systems. They showed superiority of a VCMS over functional layout, which in turn was superior to cellular layout. In their study, Kannan and Ghosh (1996b) concluded that a VCMS generally outperforms cellular and functional layout. Kannan (1998) presented that cellular layout outperformed VCMS only under conditions of low shop load, small batch sizes and high setup times.

Suresh and Slomp (2005) added the labor dimension in the study carried out by Shambu and Suresh (2000) and showed that in certain parameter ranges of dual resource constrained (DRC) setting; virtual cells can truly outperform functional and cellular layouts. Bokhorst, Nomden and Slomp (2008) explored the effect of various parameters on the flow time in small manufacturing cells with and without labor constraints.

The VCM systems implement the family oriented scheduling scheme for production using the properties of CM that combined with the routing flexibility of process layout (Kannan and Ghosh 1996). The research in the area of VCM gains momentum since a decade. This is due to meet the challenges from the turbulent market environment, which is characterized by frequent changes of the product mix driven by high customer competition, and uncertainty in demand requirements. Therefore, the approach of VCM gives considerable benefits if companies are interested in implementing manufacturing systems, which can be quickly reorganized with minimal cost and time.

3. A NEW CONCEPT OF VIRTUAL CELLULAR MANUFACTURING

3.1 Virtual Cellular Manufacturing

Virtual cellular manufacturing is a production control philosophy which is helpful to gain the advantages of the routing flexibility in job shops and the set-up efficiencies of group technology manufacturing cells in the functional layout situation. The previous studies (Kannan and Ghosh, 1996) focused on the improvement in queue related performance measures of the job shop by simply creating into virtual cells instead of converting into traditional cells. Their VCM approach involves the allocation of machines to part families based on machine idleness. Instead of this, our research addresses a new concept of design of virtual cells, which may combine the advantages of traditional manufacturing systems such as functional and cellular layouts. However, the two approaches of virtual cellular manufacturing are briefly described here along with a hypothetical problem.

3.2 Kannan and Ghosh's Approach of Virtual Cellular Manufacturing (VCM-1)

The VCM approach of Kannan and Ghosh (1996) primarily deals with family oriented scheduling rules for allocation of machines temporarily to part families based on machine idleness and the requirements of production. Initially, already arrived jobs are directly released to the job shop. When parts from a family progresses through the shop, using family oriented scheduling mechanism, machines from the various process departments are allocated temporarily to the families. Whenever there is a change in the workflow patterns, machines are reassigned between families so that cell can change their size and capacity. For implementation of various VCM configurations, various heuristics are applied for allocation of machines to part families. When allocating idle machines, priority is given to families with parts in the corresponding department queues but with no machines in the department assigned to them. Once a machine is assigned to a family, the family retains the use of machine until one of two conditions is met. Either no parts from the family remain in the corresponding department queue, or multiple machines in the department are assigned to the family while other families with parts in the queue have no machines in the department assigned to them.

3.3 Proposed Concept of Virtual Cellular Manufacturing (VCM-2)

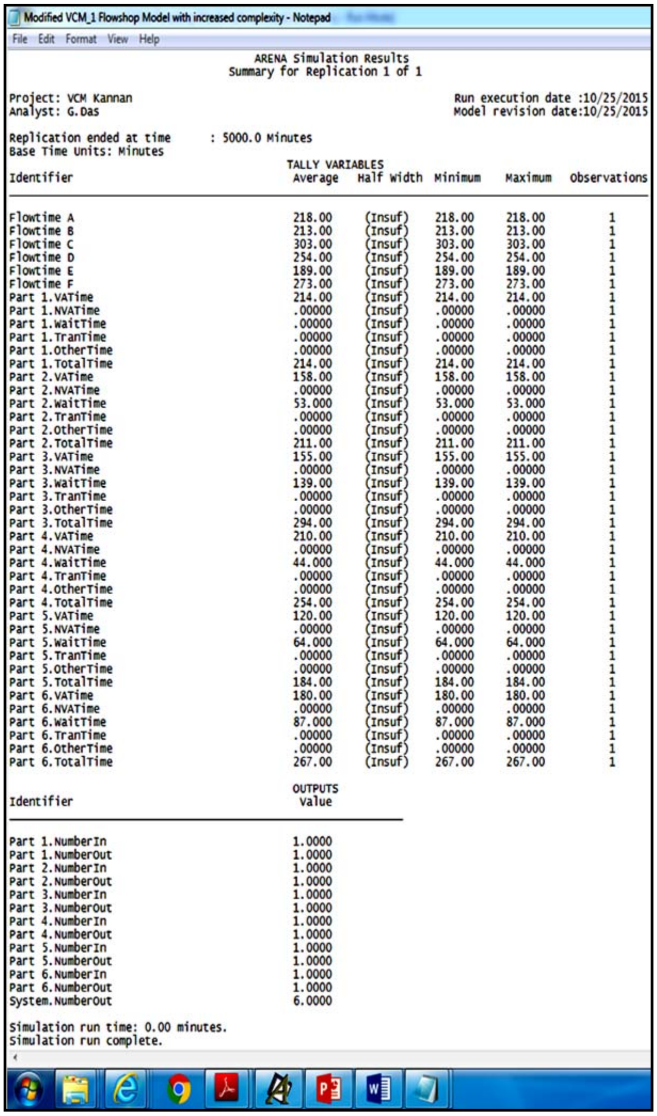
The proposed VCM approach differs from the existing concept primarily in the creation of virtual cells. In the first step of this approach, the jobs are pooled in to families according to similarities in job characteristics. Whereas in the second step, before release of each family to the shop, the number of machines that are required from each process department will be decided based on the work content. In the final step, the optimal production sequence of jobs within each family will be decided using a flow shop scheduling algorithm (Nawaz et al., 1983). Through a heuristic each family may be released to the shop. There are several possibilities for releasing a family to the shop. For instance, assume the number of jobs in each family equal to two. Within the cell the jobs of the released family will be loaded over the machines according to the step 3. But here it is worth to note that sometimes the pre decided number of machines in each department is not available by the time that the released family reaches to process department. This problem may occur some times because the required number of machines is computed beforehand based on work content criteria. If a family reaches a department buffer and if all the machines of that department are busy with some other families then in that case the family just arrived will join the department queue and will wait until a machine is idle. Once production of a particular family is completed in a cell then that virtual cell is no longer exists and the machines with in that cell are free to form another virtual cell.

4. SIMULATION STUDY

A hypothetical model for the assumed VCM was developed in the ARENA© (Kelton et al., 2010) simulation platform. Separate models were developed for each of the two VCM situations considered. The assumed situation comprises of a flow shop with three process departments. The shops contain a total of nine machines, M1 to M9 with three machines in each department, and product flow is unidirectional. For this simulation study, six part types (a, b, c, d, e, and f) belonging to two part families are considered and each part type must visit each of the three departments before exiting the system. The arrival time of each part type (alternatively called jobs) and processing times required in each department are shown in Table 1. The snapshots of simulation results obtained both VCM-1 and VCM-2 are shown in Figures 1 and 2, respectively. Snapshots for the ARENA© models developed for both VCM-1 and VCM-2 are shown in Figures 3 and 4, respectively.

Table 1: Job-departmental times

Family type	Job	Arrival time (in min)	Required Processing time in each Department (in min)		
			Dept.1	Dept.2	Dept.3
1	A	04	05	11	18
	B	02	14	08	16
	E	05	08	10	15
2	C	09	06	04	25
	D	00	16	09	05
	F	06	10	08	15



Modified VCM_1 Flowshop Model with increased complexity - Notepad

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ARENA Simulation Results
Summary for Replication 1 of 1

Project: VCM Kannan
Analyst: G.Das

Run execution date :10/25/2015
Model revision date:10/25/2015

Replication ended at time : 5000.0 Minutes
Base Time Units: Minutes

TALLY VARIABLES

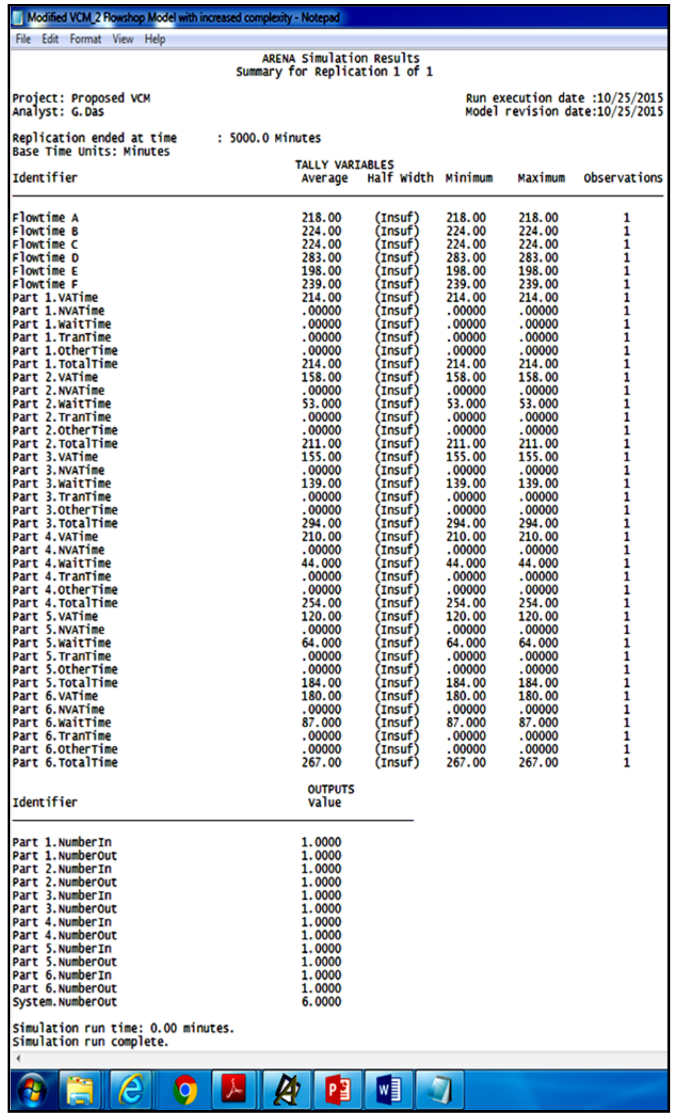
Identifier	Average	Half Width	Minimum	Maximum	Observations
Flowtime A	218.00	(Insuf)	218.00	218.00	1
Flowtime B	213.00	(Insuf)	213.00	213.00	1
Flowtime C	303.00	(Insuf)	303.00	303.00	1
Flowtime D	254.00	(Insuf)	254.00	254.00	1
Flowtime E	189.00	(Insuf)	189.00	189.00	1
Flowtime F	273.00	(Insuf)	273.00	273.00	1
Part 1.VATime	214.00	(Insuf)	214.00	214.00	1
Part 1.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 1.WaitTime	.00000	(Insuf)	.00000	.00000	1
Part 1.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 1.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 1.TotalTime	214.00	(Insuf)	214.00	214.00	1
Part 2.VATime	158.00	(Insuf)	158.00	158.00	1
Part 2.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 2.WaitTime	53.000	(Insuf)	53.000	53.000	1
Part 2.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 2.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 2.TotalTime	211.00	(Insuf)	211.00	211.00	1
Part 3.VATime	155.00	(Insuf)	155.00	155.00	1
Part 3.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 3.WaitTime	139.00	(Insuf)	139.00	139.00	1
Part 3.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 3.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 3.TotalTime	294.00	(Insuf)	294.00	294.00	1
Part 4.VATime	210.00	(Insuf)	210.00	210.00	1
Part 4.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 4.WaitTime	44.000	(Insuf)	44.000	44.000	1
Part 4.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 4.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 4.TotalTime	254.00	(Insuf)	254.00	254.00	1
Part 5.VATime	120.00	(Insuf)	120.00	120.00	1
Part 5.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 5.WaitTime	64.000	(Insuf)	64.000	64.000	1
Part 5.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 5.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 5.TotalTime	184.00	(Insuf)	184.00	184.00	1
Part 6.VATime	180.00	(Insuf)	180.00	180.00	1
Part 6.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 6.WaitTime	87.000	(Insuf)	87.000	87.000	1
Part 6.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 6.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 6.TotalTime	267.00	(Insuf)	267.00	267.00	1

OUTPUTS

Identifier	Value
Part 1.NumberIn	1.0000
Part 1.NumberOut	1.0000
Part 2.NumberIn	1.0000
Part 2.NumberOut	1.0000
Part 3.NumberIn	1.0000
Part 3.NumberOut	1.0000
Part 4.NumberIn	1.0000
Part 4.NumberOut	1.0000
Part 5.NumberIn	1.0000
Part 5.NumberOut	1.0000
Part 6.NumberIn	1.0000
Part 6.NumberOut	1.0000
System.NumberOut	6.0000

Simulation run time: 0.00 minutes.
Simulation run complete.

Fig. 1: Simulation Results of VCM-1.



Modified VCM_2 Flowshop Model with increased complexity - Notepad

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ARENA Simulation Results
Summary for Replication 1 of 1

Project: Proposed VCM
Analyst: G.Das

Run execution date :10/25/2015
Model revision date:10/25/2015

Replication ended at time : 5000.0 Minutes
Base Time Units: Minutes

TALLY VARIABLES

Identifier	Average	Half Width	Minimum	Maximum	Observations
Flowtime A	218.00	(Insuf)	218.00	218.00	1
Flowtime B	224.00	(Insuf)	224.00	224.00	1
Flowtime C	224.00	(Insuf)	224.00	224.00	1
Flowtime D	283.00	(Insuf)	283.00	283.00	1
Flowtime E	198.00	(Insuf)	198.00	198.00	1
Flowtime F	239.00	(Insuf)	239.00	239.00	1
Part 1.VATime	214.00	(Insuf)	214.00	214.00	1
Part 1.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 1.WaitTime	.00000	(Insuf)	.00000	.00000	1
Part 1.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 1.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 1.TotalTime	214.00	(Insuf)	214.00	214.00	1
Part 2.VATime	158.00	(Insuf)	158.00	158.00	1
Part 2.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 2.WaitTime	53.000	(Insuf)	53.000	53.000	1
Part 2.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 2.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 2.TotalTime	211.00	(Insuf)	211.00	211.00	1
Part 3.VATime	155.00	(Insuf)	155.00	155.00	1
Part 3.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 3.WaitTime	139.00	(Insuf)	139.00	139.00	1
Part 3.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 3.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 3.TotalTime	294.00	(Insuf)	294.00	294.00	1
Part 4.VATime	210.00	(Insuf)	210.00	210.00	1
Part 4.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 4.WaitTime	44.000	(Insuf)	44.000	44.000	1
Part 4.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 4.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 4.TotalTime	254.00	(Insuf)	254.00	254.00	1
Part 5.VATime	120.00	(Insuf)	120.00	120.00	1
Part 5.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 5.WaitTime	64.000	(Insuf)	64.000	64.000	1
Part 5.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 5.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 5.TotalTime	184.00	(Insuf)	184.00	184.00	1
Part 6.VATime	180.00	(Insuf)	180.00	180.00	1
Part 6.NVATime	.00000	(Insuf)	.00000	.00000	1
Part 6.WaitTime	87.000	(Insuf)	87.000	87.000	1
Part 6.TranTime	.00000	(Insuf)	.00000	.00000	1
Part 6.OtherTime	.00000	(Insuf)	.00000	.00000	1
Part 6.TotalTime	267.00	(Insuf)	267.00	267.00	1

OUTPUTS

Identifier	Value
Part 1.NumberIn	1.0000
Part 1.NumberOut	1.0000
Part 2.NumberIn	1.0000
Part 2.NumberOut	1.0000
Part 3.NumberIn	1.0000
Part 3.NumberOut	1.0000
Part 4.NumberIn	1.0000
Part 4.NumberOut	1.0000
Part 5.NumberIn	1.0000
Part 5.NumberOut	1.0000
Part 6.NumberIn	1.0000
Part 6.NumberOut	1.0000
System.NumberOut	6.0000

Simulation run time: 0.00 minutes.
Simulation run complete.

Fig. 2: Simulation Results of VCM-2.

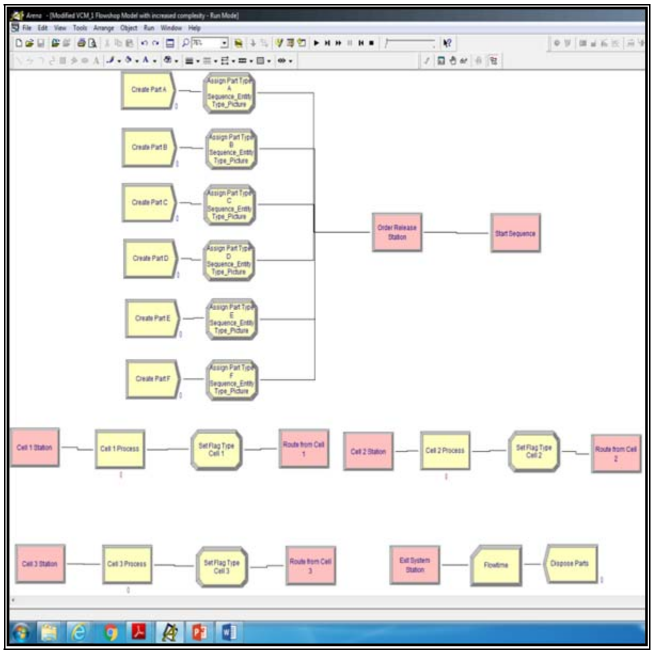

Fig. 3: ARENA© Model for VCM-1.

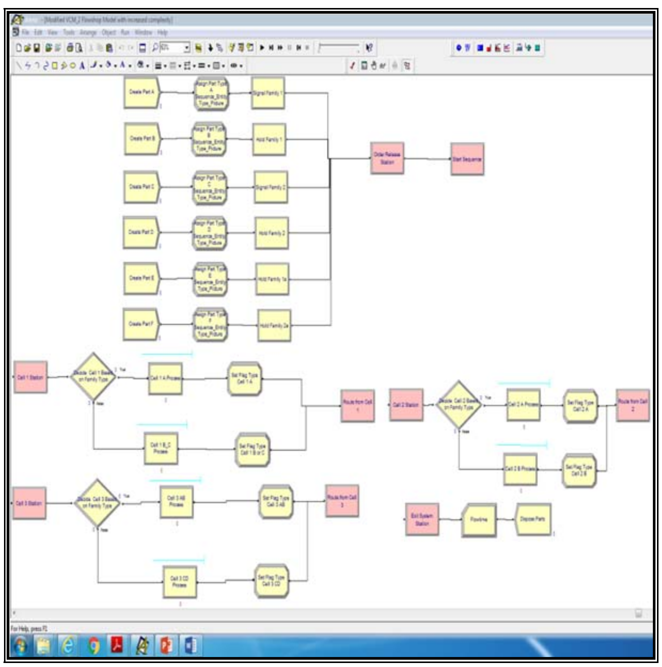

Fig. 4: ARENA© Model for VCM-2.

5. CONCLUSION

Past research has shown that it is possible to simultaneously achieve the benefits of traditional systems include cellular and functional layouts by viewing cells not as permanent, physical structures, but as temporary, 'virtual' entities. Within the virtual cell creation mechanism, right decisions for pooling of jobs into families, release of part families to the shop, sequencing of jobs within a family, and dispatching of jobs to individual machines will lead to further improvement in shop performance. The main objective of this paper is to develop and test a new concept of virtual cellular manufacturing that directly addressed these operational issues through simulation. This new concept of virtual cellular manufacturing may fits into the present day industrial practice especially within the functional layout environment in which production planning department periodically reorganize the manufacturing system without any major investment and risk.

The job-wise flow times in both configurations of VCM i.e. VCM-1 and VCM-2 are summarized in Table 2.

Table 2: Flow Times for VCM-1 and VCM-2.

Job	Flow Time (in min)	
	VCM-1	VCM-2
a	218	218
b	213	224
c	303	224
d	254	283
e	189	198
f	273	239

6. ACKNOWLEDGEMENT

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