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Implementation of an overall design of a flexible manufacturing system

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Abstract

In this study, an implementation of the design of an FMS is performed to calculate necessary number, utilization and sequence of workstations and plant layout for given production quantities of different parts, processing sequence and times. Analytical bottleneck model and rank order clustering techniques are used in the calculation and analysis of the system. Manufacturing cells are constituted for similar parts to simplify the analysis of the system and to efficient use of workstations. Results are compared with the conventional manufacturing conditions to determine the effectiveness of the implementation.

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Keywords: Flexible manufacturing; bottleneck model; workstation sequence; utilization; rank order clustering.

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1. Introduction

Flexible Manufacturing Systems (FMS) are preferred in more and more establishments with each passing day because of their numerous advantages such as low amount of stock, high competitiveness, high product quality, low manufacturing lead time (MLT), quick response to customer demands, low labor cost, etc. since they have first conceptualized during the mid 1960s. FMSs are able to manufacture a wide variety of products with much higher productivity when compared with conventional atelier type manufacturing [1]. Flexible manufacturing (FM) can be defined as a computer controlled workstation and material handling system which enables processing and/or

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assembly of a wide variety of parts quickly with minimum workstation configuration periods and maximum workstation utilization. FMSs include the material transport system, the buffer, the workpiece warehouse, human resources and others besides the processing equipment [2, 3]. A typical FMS can process one or more part families continuously and simultaneously without human intervention and is flexible enough to suit changing market conditions and product types [4]. FMSs can easily and quickly be configured to manufacture new parts or products. On the other hand, there are some important parameters that have to be considered such as financial and technological factors, educational adequateness, maintenance and spare part potentials, industrial relations, rival companies, unemployment and government policies, etc. in passing to FM. The complex structure of FMSs and quick changes in customer demands require detailed analyses of manufacturing processes. In the literature there are plenty of studies about mathematical [1, 3, 5-11, 16-19] and simulation based [1, 2, 12-15, 20-24] analysis of FMSs.

Nomenclature

BS_i	number of busy servers at station i
f_{ijk}	frequency for operation k of part j at station i
m	number of different parts
n	number of different stations
n_{tr}	average number of transports
p_j	fraction of part j in total number of parts
r	number of different operations
R_{pi}	production rate of station i
R_p^*	maximum production rate
s_i	number of servers at station i
s^*	number of servers at bottleneck station
t_{ijk}	processing time for operation k of part j at station i
t_{tr}	average transport time between servers
U_i	average utilization of station i
U_s	overall utilization
WL_i	average workload of station i
WL_{tr}	average workload of transport system
WL^*	average workload of bottleneck station

2. Theoretical Background

Manufacturing processes have to be planned carefully to obtain high quality parts/products with low cost and high speed. Analysis of a manufacturing system is a complex work which consists of determination of necessary workstations, calculation of MLTs and utilization of workstations, grouping of parts/products according to their geometrical and/or processing similarities, constituting manufacturing cells for grouped parts/products, apportioning workstations into these cells and sequencing workstations in the cells. Analysis can be performed using physical, analytical and simulation based methods. In this problem, analytical method is used to calculate above mentioned parameters.

Analytical bottleneck model and rank order clustering techniques are used in the calculation and analysis of the system. Manufacturing cells are constituted for similar parts to simplify the analysis of the system and to efficient use of workstations. Sequence of workstations in each cell is determined using Hollier Wild technique to minimize transport of work-in-processes (WIP) and thus lowering MLTs and costs.

Bottleneck model is a simple and intuitive deterministic approach that can describe FMS performance mathematically [3]. The purpose of the analysis is to determine necessary number of server at each workstation to fulfil the production rates by calculating the workloads of all stations as follows;

$$WL_i = \sum_j \sum_k t_{ijk} f_{ijk} p_j \tag{1}$$

Number of servers in the transport system has to be determined as well as in the manufacturing, assembly and handling stations. To do this, the average number of transports which is an important parameter to calculate the time spent for transfer of WIPs has to be calculated as follows;

$$n_{tr} = \sum_i \sum_j \sum_k f_{ijk} p_j - 1 \tag{2}$$

where i=1,2,…,n; j=1,2,…,m and k=1,2,…,r. In this case, workload of the transport system can be calculated as follows;

$$WL_{tr} = n_{tr} t_{tr} \tag{3}$$

Production rate of each station can be calculated as follows;

$$R_{pi} = \frac{s_i}{WL_i} \tag{4}$$

Production rate of the system can be calculated as follows;

$$R_p^* = \frac{s^*}{WL^*} \tag{5}$$

Number of busy servers at each station can be calculated as follows;

$$BS_i = WL_i R_p^* = WL_i \frac{s^*}{WL^*} \tag{6}$$

Utilization of each station can be calculated as follows;

$$U_i = \frac{WL_i}{s_i} R_p^* = \frac{WL_i}{s_i} \frac{s^*}{WL^*} \tag{7}$$

Utilization of the system can be calculated as follows;

$$U_s = \frac{\sum_{i=1}^{n} s_i U_i}{\sum_{i=1}^{n} s_i} \tag{8}$$

3. Analysis and Modeling

Mathematical analysis of the manufacturing system in which 32 different parts are produced using 7 different manufacturing and assembly processes with an inspection, a handling and a transport system is realized. 315 processes have to be performed for manufacturing of all 32 parts. Total amount of parts manufactured in a month in this facility is 258,900. Manufacturing ratios of all parts manufactured in the system is given in Table 1.

Table 1. Manufacturing ratios of the parts.

Part	P.001	P.002	P.003	P.004	P.005	P.006	P.007	P.008	P.009	P.010	P.011
Ratio	0.0355	0.0070	0.0468	0.0299	0.0630	0.0274	0.0162	0.0203	0.0463	0.0811	0.0035
Part	P.012	P.013	P.014	P.015	P.016	P.017	P.018	P.019	P.020	P.021	P.022
Ratio	0.0278	0.0454	0.0326	0.0232	0.0371	0.0261	0.0209	0.0024	0.0927	0.0338	0.0185
Part	P.023	P.024	P.025	P.026	P.027	P.028	P.029	P.030	P.031	P.032	Total
Ratio	0.0425	0.0127	0.0164	0.0046	0.0494	0.0232	0.0174	0.0695	0.0058	0.0209	1.0000

The manufacturing system works approximately 26 days per month with 2 shifts of 8 hours in a day. Efficiency of the system is calculated to be 93 % which results from maintenance, repair, deadlocks and other unexpected conditions. In Table 2; monthly production amount, production ratio, sequence, time and frequency of processes for part P.001 which are used in the analyses are given as an example.

Table 2. Manufacturing process parameters of part P.001.

Part	Monthly Production Amount	Production Ratio	Process	Process Time [sec.]	Process Frequency [-]
P.001	9200	0.0355	Loading	18	1.00
			Turning	34	1.00
			Milling	25	1.00
			Drilling	15	1.00
			Turning	92	1.00
			Drilling	24	1.00
			Assembly	70	1.00
			Inspection	42	0.20
			Unloading	10	1.00

Average number of transports is used to calculate the workload of transport system. In Table 3, average number of transports in each cell and in the system is given. Average time of a transport between two neighbour servers is taken to be 9 seconds. Unloading and loading times aren't included in transport times.

Table 3. Average number of transports in the cells and system.

	Average number of transports [-]						
	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**System**
n_{tr}	46.60	38.70	26.40	63.00	20.60	60.10	255.40

Planning the manufacturing of 32 parts which have considerably different work flows on an individual basis should be ineffectual. For this reason, parts are grouped into 6 cells according to their process similarities using rank order clustering method as shown in Table 4.

Workloads of stations is an important parameter to determine the necessary number of servers in a station. In Table 5, workloads of all stations in each cell and in the system is given.

Table 4. Formation of manufacturing cells according to process similarities.

		St_H	St_T	St_M	St_D	St_G	St_F	St_C	St_I	St_A	St_Tr
Cell 1	P.004	X	X	X	X		X	X	X	X	X
	P.008	X		X		X	X	X	X	X	X
	P.011	X	X	X	X	X	X	X	X	X	X
	P.014	X	X		X	X	X	X	X	X	X
	P.023	X	X	X	X	X	X	X	X	X	X
Cell 2	P.009	X	X	X	X		X	X	X		X
	P.012	X	X	X	X	X	X	X	X		X
	P.017	X		X			X	X	X		X
	P.026	X	X		X	X	X	X	X		X
	P.032	X	X	X	X	X	X	X	X		X
Cell 3	P.007	X	X		X	X	X		X		X
	P.016	X	X	X		X	X		X		X
	P.020	X	X	X		X	X		X		X
	P.027	X	X	X	X	X	X		X		X
Cell 4	P.002	X	X	X	X	X		X	X	X	X
	P.005	X			X			X	X	X	X
	P.006	X	X	X	X	X		X	X	X	X
	P.015	X	X	X	X	X		X	X	X	X
	P.018	X	X	X	X	X		X	X	X	X
	P.028	X	X		X	X		X	X	X	X
	P.030	X	X	X	X	X		X	X	X	X
Cell 5	P.001	X	X	X	X				X	X	X
	P.010	X	X	X		X			X	X	X
	P.021	X	X	X	X	X			X	X	X
Cell 6	P.003	X	X	X	X	X		X	X		X
	P.013	X	X	X	X	X		X	X		X
	P.019	X	X	X	X	X		X	X		X
	P.022	X	X		X	X		X	X		X
	P.024	X	X	X	X	X		X	X		X
	P.025	X	X	X	X	X		X	X		X
	P.029	X		X		X		X	X		X
	P.031	X	X	X	X	X			X		X

St: Station, P: Part, H: Handling, T: Turning, M: Milling, D: Drilling, G: Griding,
F: Forging, C: Cutting, I: Inspecting, A: Assembling, Tr: Transporting

Table 5. Workloads of stations.

	Workload [sec.]						
	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**System**
WL_H	28.00	28.00	28.00	28.00	28.00	28.00	28.00
WL_T	61.39	60.20	109.72	60.43	99.99	84.35	80.07
WL_M	99.73	101.08	96.38	83.21	85.65	123.64	97.22
WL_D	30.27	35.12	6.46	46.87	16.85	31.49	28.29
WL_G	21.12	10.65	32.25	32.13	22.91	41.06	28.13
WL_F	23.07	21.69	18.64	-	-	-	10.25
WL_C	62.23	51.76	-	49.31	-	65.77	36.13
WL_I	6.56	5.74	4.30	5.72	8.99	6.91	6.24
WL_A	27.52	-	-	56.45	73.32	-	27.79
WL_{tr}	80.96	69.49	59.53	78.01	59.95	68.18	69.36

Production rate of a station represents the number of parts in a specific time period that a server is able to manufacture. Production rates of all stations with only 1 server in each cell and in the system is given in Table 6.

Number of busy servers at all stations in each cell and in the system is given in Table 7. Rounding up these values to the nearest bigger integer gives necessary number of servers.

Ratio of busy servers to the necessary number of servers gives the utilization of stations. In Table 8, utilization of each station in the cells and in the system with overall utilization of the cells and the system is given.

Table 6. Production rates of stations.

	Production rate [parts/min.]						
	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**System**
R_{pH}	2.14	2.14	2.14	2.14	2.14	2.14	2.14
R_{pT}	0.98	0.10	0.55	0.99	0.60	0.71	0.75
R_{pM}	0.60	0.59	0.62	0.72	0.70	0.49	0.62
R_{pD}	1.98	1.71	9.28	1.28	3.56	1.91	2.12
R_{pG}	2.84	5.63	1.86	1.87	2.62	1.46	2.13
R_{pF}	2.60	2.77	3.22	-	-	-	5.85
R_{pC}	0.96	1.16	-	1.22	-	0.91	1.66
R_{pI}	9.14	10.46	13.96	10.48	6.67	8.69	9.61
R_{pA}	2.18	-	-	1.06	0.82	-	2.16
R_{pTr}	0.74	0.86	1.01	0.77	1.00	0.88	0.87

Table 7. Number of busy servers at stations.

	Number of busy servers [-]						
	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**System**
BS_H	0.67	0.65	1.02	1.22	0.78	0.86	5.20
BS_T	1.47	1.41	3.99	2.63	2.80	2.60	14.88
BS_M	2.39	2.36	3.50	3.62	2.40	3.80	18.07
BS_D	0.72	0.82	0.23	2.04	0.47	0.97	5.26
BS_G	0.51	0.25	1.17	1.40	0.64	1.26	5.23
BS_F	0.55	0.51	0.68	-	-	-	1.74
BS_C	1.49	1.21	-	2.15	-	2.02	6.87
BS_I	0.16	0.13	0.16	0.25	0.25	0.21	1.16
BS_A	0.66	-	-	2.46	2.05	-	5.17
BS_{Tr}	1.94	1.62	2.16	3.39	1.68	2.10	12.89

Table 8. Utilization of stations.

	Utilization [%]						
	Cell 1	**Cell 2**	**Cell 3**	**Cell 4**	**Cell 5**	**Cell 6**	**System**
U_H	67.05	65.44	50.86	60.91	78.30	86.15	86.75
U_T	73.49	70.35	99.65	87.64	93.21	86.50	99.22
U_M	79.60	78.75	87.54	90.52	79.85	95.10	95.11
U_D	72.49	82.07	23.48	67.97	47.12	96.87	87.66
U_G	50.58	24.90	58.57	69.90	64.08	63.16	87.14
U_F	55.25	50.69	67.72	-	-	-	95.31
U_C	74.51	60.48	-	71.51	-	67.45	95.94
U_I	15.72	13.41	15.62	24.91	25.15	21.24	58.02
U_A	65.90	-	-	81.88	68.35	-	86.10
U_{Tr}	96.93	81.20	72.09	84.86	83.82	69.92	99.18
U_s	70.38	64.06	71.71	76.60	73.77	76.81	93.28

Distributing servers to the cells reduces the efficiency of the stations, so utilization of each station in the system is much higher than the utilization of stations in the cells, as seen from Table 8. Nevertheless, splitting system to cells is important for minimizing transports and MLTs and simplifying manufacturing process. Using some of the servers commonly between neighbour cells considerably decreases necessary number of servers as seen in Table 9.

Necessary number of servers in the conventional atelier type system and in the flexible cellular system and in the ideal system are given in Table 10. In the cellular system, cells can either be independent from each other or can be dependent because of common usage of some servers to decrease necessary number of servers and increase utilization as it is mentioned before.

Sequence of servers in a cell is also very important in reducing transport times. Hollier Wild technique is used to minimize backward motion in the cells which increases the motions, transport times and thus MLTs. In Figure 1, motions of parts P.001, P.010 and P.021 are shown according to enhanced server alignment in a line type cell design.

Table 9. Number and distribution of necessary servers in the cells.

		Number of servers									
		St_T	**St_M**	**St_D**	**St_G**	**St_F**	**St_C**	**St_A**	**St_Tr**		
St_H Loading 4	**Cell 3**	4	4	-	-	-	-	-	2	**St_I 2**	**St_H Unloading 3**
	Common 2-3	-	-	1	1	1	-	-	1		
	Cell 2	1	2	-	-	-	1	-	1		
	Common 1-2	1	1	1	1	1	1	-	-		
	Cell 1	1	2	-	-	-	1	1	2		
	Common 1-4	-	-	-	-	-	-	-	-		
	Cell 4	3	3	2	2	-	3	2	4		
	Common 4-5	-	1	1	-	-	-	1	-		
	Cell 5	3	2	-	-	-	-	2	1		
	Common 5-6	-	-	-	1	-	-	-	1		
	Cell 6	3	4	1	1	-	2	-	2		
	Total	16	19	6	6	2	8	6	14		86

Table 10. Comparison of the necessary number of servers.

	Necessary number of servers [-]										
	St_H	**St_T**	**St_M**	**St_D**	**St_G**	**St_F**	**St_C**	**St_I**	**St_A**	**St_Tr**	**Total**
Conventional atelier type MS	9	18	23	9	10	3	11	6	8	20	117
FMS with independent cells	8	17	21	8	9	3	10	6	7	16	105
FMS with common server usage	7	16	19	6	6	2	8	2	6	14	86
Ideal system	6	15	19	6	6	2	7	2	6	13	82

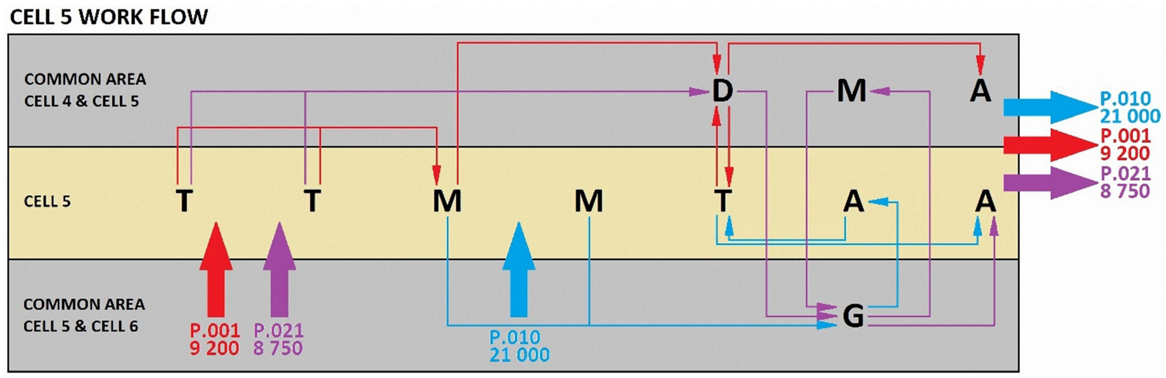

Fig. 1. Sequence and work flow for Cell 5.

4. Results and Discussions

Analytical results are compared with the conventional manufacturing conditions of the system to determine the effectiveness of the implementation. Obtained results showed that, total travel distance and time of the parts in the system decreased dramatically in the FMS. Backward motion in all cells are calculated to be under 20 % for all parts. Moreover, efficiency of the system is increased by decreasing idle times of the workstations. MLTs, part/product costs, stocking amounts and labor needs are decreased in this way. Total utilization of the system is calculated to be 95.3 % which is approximately 35 % higher than the existing conventional atelier type manufacturing system.

The study presents an overall analysis procedure for modeling and design of an FMS. This procedure should be useful for different types of manufacturing systems as well as FMSs. Carrying out this procedure provides insight on the results of passing to FM from the aspects of production ratio, efficiency and cost.

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