MATERIAL HANDLING COST CONSIDERATION IN PROCESS PLAN SELECTION FOR RECONFIGURABLE MANUFACTURING SYSTEM

Sajid Ullah Butt, Aamer Ahmed Baqai, Syeda Naela Fatima, Hasan Aftab Saeed

ABSTRACT

In today's market, ever-changing products and demands are major concerns for every manufacturer. Reconfigurable Manufacturing Systems (RMS) are so designed as to have customized flexibility and cost-effective reconfiguration whenever a design change in products/product families is needed. In RMS, the process plan is designed such that changes in demand or features etc. can easily be reflected without major loss in manufacturing time or cost. The costs usually included are machine usage, tool usage, machine change, tool change costs etc. All the parameters related to these costs become a part of the process plans. The focus of this research is to include material handling equipment such as transport and positioning equipment in the process plans and hence, to include their usage cost in the overall mathematical model. This will lead to a more accurate design of process plan particularly in terms of MHE related to each machine required to produce a part. The inclusion of MHE cost gives an idea about the impact of these equipment on overall cost of manufacturing. The presented model will help in the decision-making process of allocating part to machines & also allocating MHE to each machine considered in the process plan.

KEYWORDS: *RMS, Process Planning, Material Handling System*

INTRODUCTION

With the rise of customization in designs, the main issue being faced by the market nowadays is the shorter life of product due to unpredictable variations in demand. To minimize the follow-up time, companies need to minimize time required to reconfigure or design to begin production and yet be able to beat the competition. The outcome was the idea of reconfigurable manufacturing systems (RMS). These systems were designed to have customized flexibility and cost-effective reconfiguration whenever a design change in products/product families is needed. The addition, removal or modification of machine modules, configurations, machines & material handling units and other components of the system leads to achievement of the goals offered by RMS (Shabaka and Elmaraghy, 2007; Zhang *et al.,* 1997).

Shabaka and Elmaraghy (2007) classified reconfiguration in manufacturing systems into two classes; hard and soft. Hard or Physical reconfiguration is at the system level, involving machines, machine tools, material handling systems & their parameters. Soft or logical reconfiguration is at the control level & deals with changes in the controller & its relevant architecture in face of change in demands.

Process Planning

Process planning is defined by SME as, "The systematic determination of the methods by which a product is to be manufactured economically and competitively". Process Planning is an intricate task that has a vital role in converting design information into manufacturing process and choosing the best possible sequence of operations.

Multiple operation sequences can be generated, satisfying all constraints to produce designed part but all of them are not optimal sequences and the best one has to be chosen. The deciding factors for optimum sequence selection can be different, for example, minimum cost, minimum change-overs, minimum lead time etc. But most commonly, optimal solution is the one with minimum manufacturing cost while following the precedence constraints.

According to Zhang et al. (1997) in process planning operation selection and operation sequencing decision making tasks involved are to be carried out side by side to achieve feasible process plan. Shabaka and Elmaraghy (2007) established an approach for selecting suitable configuration for different machines to produce different parts and features, as per the required machine capabilities in process planning. It was also proposed grouping operations into operation clusters that have

Department of Mechanical Engineering, College of E&ME National University of Science & Technology (NUST), Islamabad, Pakistan

logical constraints and tolerance constraints (Fig. 1).

Shabaka and Elmaraghy (2008) proposed a new process planning method for dissimilar manufacturing systems, based on operation sequencing and operation selection. For process planning of RMS, the machine configuration variable has been presented to the process planning feasibility problem. Ling et al. (2000) carried out work regarding the application of process planning to the new standard of RMS. As machine tool is designed

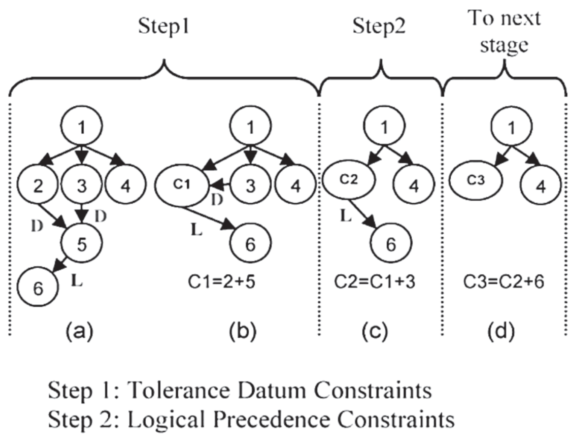


Fig. 1: Operation Clustering Procedure (Shabaka and Elmaraghy, 2007)

around the part, they inquired processes that could be carried out using gang spindle drilling.

For optimization of process plans, Li, et al. (2002) proposed a hybrid GA & SA methodology which simultaneously reflects the steps of selection of machining capabilities, setup plans and the sequencing of operations for prismatic parts with the aim of selecting the most optimum process plan. Ong and N. A. Y. C. (2002) developed an approach for the optimization of set-up planning via hybrid GA and SA (simulated annealing) method in a dynamic manufacturing environment. Also, their proposed system can do better re-setup planning upon the dynamic changes of the resources of workshop.

Later, Shabaka and Elmaraghy (2008) emphasized that to attain the lowest cost all the parameters should be considered at the same time in the optimization model. The objective function for their optimization problem was to minimize the total cost of machining which included the machine usage cost, tool usage cost, machine change cost, tool change cost & setup change cost. Various cost indices were considered in cost calculation.

MATERIAL HANDLING SYSTEM

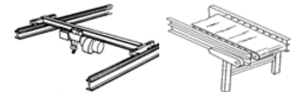
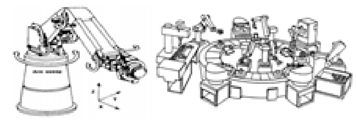
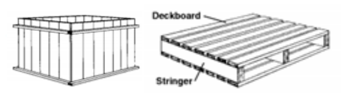
Material handling (MH) involves "short-distance movement that usually takes place within the confines of a building such as a plant or a warehouse and between a building and a transportation agency." As opposed to manufacturing which produces "form utility" by operations such as fabrications, assemblies, by shape, from & material makeup modification (Shabaka and Elmaraghy, 2008).

The material handling system is an important aspect of a manufacturing facility, where it connects & crosses various departments in the facility. While considering the design of a manufacturing system, it is essential to consider the MH system design, as MH accounts for about 20-50% of the over-all operating costs in manufacturing systems. Reduction in productivity & longer lead times, among other negative effects, can be a result of inappropriate selection of material handling equipment. MH equipment selection models suffer from a deficiency of models and solution practice (Ling *et al.*, 2000).

It is essential to include the material handling equipment with each machine within a process plan. An important aspect of considering MHE in process plans is the consideration of its cost in the process planning stage. To consider the MHE in planning stage, it is necessary to consider which type of MH equipment is available for performing various material handling activities. Generally, MHE is classified into the following five types: Transportation, Handling, Unit load formation & Storage Equipment (Shabaka and Elmaraghy, 2008). The function and examples of each type is summarized in Table 1.

Keeping in view this importance of MHS, Paulo et al. (2002) presented planning models through which some details of design were generated. Their purpose was to select a sequence of machines and operations and load them for the manufacturing of specific family of parts and then choosing an appropriate material-handling system for handling of parts at these machines or in-between these machines. The model is solved to define the material handling equipment that can perform all the operations

Table 1: Material Handling Equipment Function

Material Handling Equip.	Function	Example
Transportation equipment	carrying raw material, work-pieces, final product	 Cranes, Trucks, Conveyors etc.
Handling equipment	handling of material for subsequent handling, machining etc.	 Light load robot, Heavy load Robot, Rotary Index Table etc.
Unit load formation equipment	Restricting material when transported or stored as a unit/single load	 Crates, Pallets, Cartons etc.
Storage Equipment	containing or buffering materials for some duration	 Frames & Racks

of material handling. The selection of material handling equipment based on its ability to perform the material handling functions and if the equipment is compatible to handle the part type with some major product characteristics, is made by the model.

Sujono and Lashkari (2007) presented a mathematical model to solve the problem of operation allocation to machine and selection of material handling equipment side by side. The reasons being to minimize the total costs associated with operations, machine configurations and material handling and to maximize the compatibility of part types with material handling equipment by assigning material handling equipment according to the material handling operation. The costs considered were operation cost, machine setup cost and MH cost.

After the study of above research works, it was felt that there is a need to include the cost of material handling in process plan as well as cost model that depicts the manufacturing setup for machining in the most comprehensive manner. Hence, the proposed work aims to modify the process plan & cost consideration proposed by Shabaka and Elmaraghy (2008) & to include the material handling system/equipment at both the process plan & cost model generation level. In the next sections, this modification will be explained in detail and finally the results obtained will be discussed and compared.

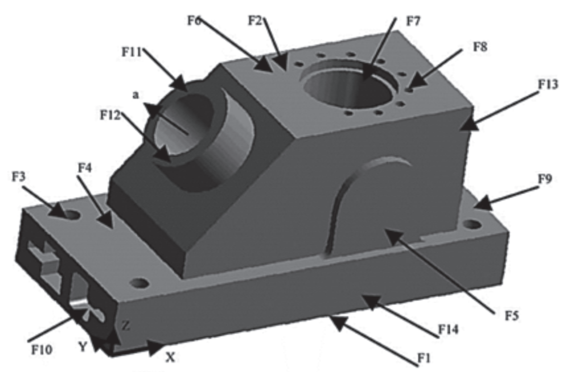


Fig. 2: Part Features ANC-101 [3]

MACHINE CONFIGURATIONS GENERATION

The determination of machine configurations for the machining of a part with certain features is a multi-step process which involves various inputs, application of these inputs at different stages which leads to an output in the form of machine structures.

The steps involved in machine configuration

Table 2: Features for part ANC-101

Feature	Description	Op.	Op.ID	TAD
F1	Planar surface	M	1	+Z
F2	Planar surface	M	2	-Z
F3	Four holes arranged as a replicated feature	D	3	+Z,-Z
F4	A step	M	4	+X, -Z
F5	A protrusion (rib)	M	5	+Y,-Z
F6	A protrusion	M	6	-Y, -Z
F7	A compound hole	D	7	-Z
		R	8	-Z
		B	9	-Z
F8	Nine holes arranged in a relicated feature	D	10	-Z
		T	11	-Z
F9	A step	M	12	-X, -Z
F10	Two pockcts arranged as a replicated feature	M	13	+X
F11	A boss	M	14	-a
F12	A compound hole	D	15	-a
		R	16	-a
		B	17	-a
F13	A pocket	M	18	-X
F14	A compound hole	R	19	+Z
		B	20	+Z

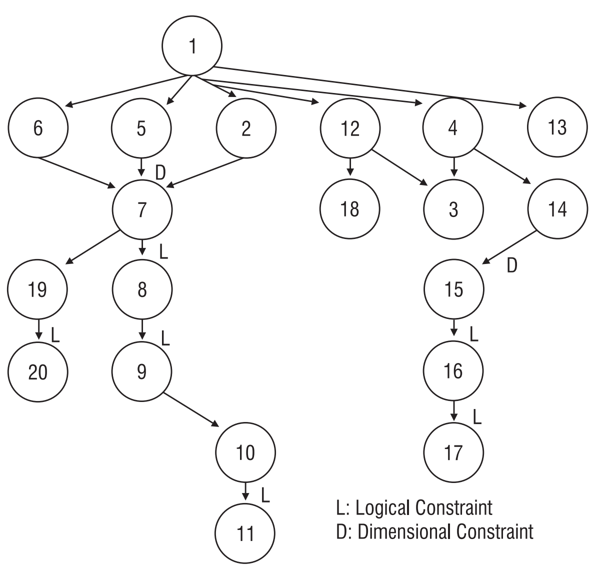
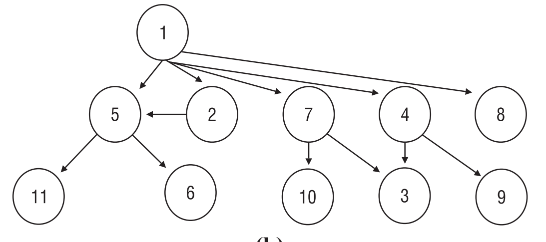


Fig. 3: Precedence Relationships for ANC-101 (Shabaka and Elmaraghy, 2008)

Clusters	Operations
OC1	1
OC2	2
OC3	3
OC4	4
OC5	5,6,7,8,9
OC6	10,11
OC7	12
OC8	13
OC9	14,15,16,17
OC10	18
OC11	19,20

(a)



(b)

Fig. 4: (a) Operation involved in Operation Clusters (b) Operation cluster precedence (Shabaka and Elmaraghy, 2008)

generation, as proposed by (Shabaka and Elmaraghy, 2007) are discussed below along-with their application on test part ANC-101.

1. Identify all the features, required machining operations & possible TAD for each operation. For ANC 101 this is shown in Fig. 2 & Table 2

2. Plot the precedence graph (Fig. 3)

3. Generate operation clusters by combining operations with datum & logical constraints into clusters and generate OC precedence Graph (Fig. 4)

4. Generate machine tool structure starting with the matrices for Operation Cluster which identify the operations present in each cluster and the possible TADs. These are the ROC & CAP matrices. The CAP matrix gives information about the capabilities a candidate machine should possess to be able to perform the operations in each individual cluster. ROC row matrix represented as

ROCi = [OP +x - x +y -y +z -z]

Here the "i" shows the OC number, OP shows the operation number in the OC and ±x, ±y & ±z show the possible directions along the x, y & z axis in which the tool must approach the part for performing an operation

$CAP_{i,p}$: Matrix representing the capability required for a machine to perform case p of operation cluster i. The matrix is a 2 by 3 matrix in which the 1st row shows the minimum positive rotation angle around x, y, z axis (or A, B, C); whereas the 2nd row show the negative angle required

8. Determine the angle of rotation or capability required for all operations in the operation cluster. This will determine all the possible machines capable of performing each operation.

9. Repeat Steps 4 & 5 for each operation cluster.

Following the method proposed by (Shabaka and Elmaraghy, 2007), a table was generated which shows each operation cluster giving the possible machine configurations required to generate the features of the part. A sample of the table for operation cluster 5 is shown in Table 3.

PROCESS PLAN GENERATION

The process plan is made up of 8 strings or arrays

Table 3: An example of machine requirements for OC5 (Fig. 4a) for ANC-101

OC5	From CAP5,1, CAP5,2, & CAP5,4
OP = 5	Machines capable of rotating ± 90o about A, +90 about A & -90 about A respectively, are possible candidates for OC5.
6	
7	
8	
9	
ROC5 = 5 0 0 1 0 0 0	CAP5,3, shows that a machine with no rotational axis of worktable is also a candidate
5 0 0 0 0 0 1	
6 0 0 0 1 0 0	
6 0 0 0 0 0 1	
7 0 0 0 0 0 1	
8 0 0 0 0 0 1	
9 0 0 0 0 0 1	
NR5= 4	
CAP5,1, =	90 0 0 90 0 0
CAP 5,2, =	90 0 0 90 0 0
CAP 5,3 =	0 0 0 0 0 0
CAP 5,4, =	0 0 0 90 0 0

Following the same procedure ROC and CAP matrices are generated for each OC and the minimum capabilities required by a machine to perform each OC are determined. The list of available machines and tools is shown in & the capable machines shown in Table 5 which were selected for each process plan. Where M3 & M4 are both 4 axis RMT but M3 is capable of part rotation about x-axis (A rotation), while M4 is capable of part rotation about y-axis (B rotation).

The output of this section serves as an input for the process plan generation and cost calculation model which is presented in the following sections.

as shown in Fig. 5.

1. First array represents the Operation Cluster sequence

2. Second array represents the machine selected

3. Third array represents the configuration of the machine selected

4. Fourth array represents the material handling equipment allocated for transportation (TE). The MHE is chosen using compatibility weights given in Table 6. The values were taken from Paulo *et al.,* 2002). Where values 0 to 5 show a compatibility of least compatible to most compatible for the given material handling operation. For example, light load robot is most compatible for loading/ unloading operations but least suitable for transportation over some distance. Similarly, Fork lift truck is least suitable for loading/ unloading operations but most suitable for transportation over some distance.

5. Fifth array represents the material handling equipment allocated for handling/positioning (PE) chosen from compatibility weights given in Table 7. The values were taken from Paulo et al., 2002). The rating values from of 1-5 show least suitable to most suitable. For example, the light duty belt conveyor (rating 2) is less suitable for handling parts of large mass/ dimension as compared to forklift truck (rating 5); which is most suitable for large mass/ dimension.

6. Sixth array represents the operations sequence

7. Seventh array represents the TAD for each tool used.

8. Eighth array represents the tool used for each operation.

Fig. 5: Process Plan Representation

OC sequence	OC1	OC4		OC2	OC5			
Machine	M1	M1		M1	M5			
Configuration	1	2		1	4			
TE	E1	E1		E1	E2			
PE	E4	E4		E6	E6			
OP Sequence	1	4	5	2	6	7	8	9
Tool used	-z	-z	z	x	-z	-z	-z	-x
TAD	1	1	4	6	2	1	1	3

Table 4: Available machines & tools and their respective cost (Shabaka and Elmaraghy, 2007).

ID	Type	Cost	ID	Type	Cost
M1	1-spidle 3-axis	760	C1	Drill 1	7
M2	1-spidle 3-axis RMT	860	C2	Drill 2	5
M3	1-spidle 4-axis RMT	1010	C3	Drill 3	3
M4	1-spindle 4 RMT	1010	C4	Drill 4	8
M5	1-spindle 5axis RMT	1110	C5	Trapping Tool	7
M6	Drill press	385	C6	Mill 1	10
	MCI=0.1 x machine		C7	Mill 2	15
	MCCI	160	C8	Mill 3	30
	TDCCI	100	C9	Ream	15
	TCCI	20	C10	Boring tool	20

Table 5: Capable machine for each case of an OC (Shabaka and Elmaraghy, 2007).

OC	1	2	3	4	OC	1	2
1	M1,M2,M3, M4, M5, M6				7	M5, M6	M1, M2, M3, M4, M5, M6
2	M1, M2, M3, M4, M5, M6				8	M5, M6	
3	M6	M1, M2, M3, M4, M5, M6			9	M3, M4, M6	
4	M5, M6	M1, M2, M3, M4, M5, M6			10	M5, M6	
5	M3, M5	M3, M6	M3, M4, M6	M1, M2, M3, M4, M5, M6	11	M1, M2, M3, M4, M5, M6	
6	M1, M2, M3, M4, M5, M6						

Table 6: Compatibility based on suitability of MHE according to the type of MH operation to be performed

MHE ID	Equipment	(un) Load	Transportation
E1	Light-load robot	5	0
E2	Human	5	0
E3	Heavy-load robot	5	0
E4	Powered hand truck	0	5
E5	Forklift truck	0	5
E6	Roller belt conveyor	0	5
E7	Light-duty belt conveyor	0	5

Table 7: Rating based on suitability to handle part type based on mass/dimension

MHE ID	Equipment, e	Mass/linear dimension
E1	Light-load robot,	1
E2	Human	2
E3	Heavy-load robot	4
E4	Powered hand truck	3
E5	Forklift truck	5
E6	Roller belt conveyor	2
E7	Light-duty belt conveyor	2

The string representation of the parameters shown in steps 1, 2, 3, 6, 7 and 8 representing the OC sequence, machine selected, configuration selected, OP sequence, tool used & TAD respectively, were the representation proposed by Shabaka, et al., [3]. The strings added in the process plan representation in the proposed work are the strings shown in steps 4 & 5 representing the transportation equipment & positioning equipment.

COST MODEL

Shabaka and Elmaraghy (2008) calculated the cost Eq. (1) as machine usage cost, tool usage cost, material handling cost, tool change & setup change cost but in their model, fixed value was assumed for material handling cost. In this work, a mathematical model is proposed to calculate the material handling cost in the form of unloading the part, transporting it between stations and loading the part on next station.

TC = MUC+TUC+MCC+TCC+MHC (1)

Machine Usage Cost

MUC is the cost of using a machine for a certain operation cluster in a specific configuration. The machine cost index is a constant that considers the costs such as the initial cost of using the machine, fixture costs, etc. However, this is not the case in practical scenarios as this cost is greatly affected by the machining time required. Still, a machine-based constant index can be used instead of the real cost to reflect its importance in the overall cost. The equation (2) shows MUC calculation.

$$MUC = \sum_{i=1}^{NOC} CM_{mi}(C_i) \, \mathrm{x} \, \mathrm{MCI} \quad (2)$$

Tool Usage Cost

TUC is the cost of using a tool for a certain operation multiplied by the Tool cost index which is given in equation (3)

$$MUC = \sum_{x=1}^{NOC} CT(t_x) \, \mathrm{x} \, T\,\mathrm{CI} \quad (3)$$

Tool Change Cost

A tool change is required when two consecutive operations performed on the same machine use different tools.

For a CNC machine with a tool magazine installed the tool change is automatic. But in most manual machines the tool must be changed manually so some sort of material handling equipment may be required to do so. However, in this research paper a constant Tool Change Cost Index (TCCI) is considered irrespective of the type of machine used as the required parameters are not available at this stage. The TCC is calculated from equation (4)

TCC= TCCI ×Total number of Tool Changes within the same machine (4)

Setup Change Cost

SCC is incurred when a TAD is changed for a certain operation. In a 4 or 5 axis CNC machine the orientation can be changed according to the specified TAD for that operation. But in manual machine the TAD has to be changed manually by changing the orientation of the work-piece for which some sort of material handling equipment may be required. However, in this paper a constant Setup Change Cost Index is considered irrespective of the type of machine used as the required parameters are not available at this stage. Equation (5) is used for SCC calculation.

SCC= SCCI × Total number of TAD changes within the same machine (5)

Material Handling Cost

The costs considered in the proposed work instead of the machine change cost is the MHC which is incurred when a machine change is required between machining operations for certain operation clusters. The types of equipment considered in this mathematical model are the handling equipment & transportation equipment. The details of the cost functions are given below from equation (6) to (9).

Nomenclature

i, j: index for OC number, i, j=1..., NOC

x, y: index for OP number, x, y=1..., NOP

m = {1, 2, …, no of machines available}

t = {1, 2, …, no of tools available}

t_x : tool used for operation, x

c_i: Configuration of machine used for OC, i. [3]

e_a= {1,2, …, NMH}

a,b: index for material handling number

The cost of handling for unloading the part from the previous machine

CUL(ea)×MHI× α (MS(i),MS(i+1)) (6)

Where,

CUL is the cost for unloading equipment e_a

MHI is the material handling cost index

The cost of transporting the part to the next machine in sequence

$$CT(ea)\times MHI\times \alpha(MS(i),MS(i+1)) \quad (7)$$

Where,

CT is the cost for transportation equipment, e_a

The cost of handling for loading the part on that machine so the next machining operation in the operation sequence can be carried out.

$$CL(ea)\times MHI \times \lambda(MS(i),MS(i-1)) \quad (8)$$

Where, CL is the cost for loading equipment e_a

The overall machine handling cost will also include the handling cost for the initial loading of part on the machine for the first operation and the handling cost for the final unloading of part on the machine for the last operation in the process plan.

$$MHC = LC(e_{m1}) + \sum_{i=1}^{NOC-1} \left\{ \begin{array}{l} [CT(e_a)\times MHI\times \alpha(MS(i),MS(i+1))] \\ +[CL(e_a)\times MHI\times \lambda(MS(i),MS(i-1))] \\ +[CUL(e_a)\times MHI\times \alpha(MS(i),MS(i+1))] \end{array} \right\} + ULC(e_{mNOC}) \quad (9)$$

Where,

- $LC(e_{m1})$ is the loading cost of the material handling equipment for the machine chosen for 1st operation cluster
- $ULC(e_{mNOC})$ is the unloading cost of the material handling equipment for the machine chosen for the last operation cluster.
- α and λ are the decision variables having the value;

  $\alpha(a,b)=1$ if $a\neq b$

  $\alpha(a,b)=0$ if $a=b$

  $\lambda(a,b)=1$ if $a\neq b$

  $\lambda(a,b)=0$ if $a=b$

PROCESS PLAN GENERATION FOR ANC-101

Following the process plan generation process, five process plans (Fig. 6-10) were generated for part ANC-101 in the current work.

1. The first part of process plan consists of operation cluster sequence which was generated from the OC precedence graph shown in Fig. 4.
2. The second part shows the machine selected for each OC chosen from the list of capable machines as shown in Table 4. For example, in Process Plan 1 (Fig. 6) the first three OCs were assigned to machine M1, the next three to M4, OC 6 & OC11 to M6, OC 10 to M4 & final two OCs to M3 as shown in Fig. 6.
3. The third part of the process plan shows the machine configuration used meaning which case of the capable machines is chosen from *Table 5*
4. The fourth part of the process plan is the material handling equipment chosen for transport (TE). From the table of compatibility (*Table 6*), for transportation the most suitable equipment is E4 to E7 and the most compatible equipment according to low to medium linear mass/ dimension are the roller belt conveyor (E6) & light belt conveyor (E7) (*Table 7*). So, each machine is allocated either of these two MHE randomly, whenever a machine change is required between two adjacent OCs.
5. The fifth part is the material handling equipment for positioning (PE). From the compatibility table for positioning the most suitable equipment are, E1 to E3 and the most compatible equipment according to low to medium linear mass/ dimension are the light load robot (E1) & human (E2) (*Table 7*). So, each machine is allocated either of these randomly, whenever unloading from machine or loading on a machine is required during machine change.
6. The sixth part shows the operation sequence within an OC which must not violate the operation precedence graph as shown in Fig. 3. The seventh & eighth part are related to the tool approach direction required for each operation to & the tool used for

each operation, respectively. The TAD for each operation (feature) is given in Table 2. The tool used is according to the feature and can be selected from the list of tools given in Table 4.

Five process plans (Fig. 6-10) are generated following these steps and changing the OC sequence, machine used, TE & PE used, operation sequence, TAD & tool used without violating any conditions.

COST CALCULATION OF PROCESS PLANS FOR ANC-101

For each process plan, equations (1) to (9) are applied to determine the Machine Usage Cost, Tool Usage Cost, Tool Change Cost, Setup Change Cost & Material Handling Cost in terms of Transportation Cost & Positioning Cost. The Machine Change Cost is not considered. Table 8 gives respective cost calculations for all five process plans.

Cost Comparison

The costs for each process plan for four cases are considered and plotted in Fig. 8 and 9. First out of four cases does not consider MHC but a constant value of MCC as proposed by Shabaka [1]. In remaining three cases, MCC is replaced with proposed MHC with the value of MHI is taken as 50, 75 and 100 for cases 2, 3 and 4 respectively.

From Fig. 8 and 9, it can be seen that by increasing the effect of MHI the overall costs increase especially in those process plans where machine changes are more than other process plans. For example, the change of MHI value has more effect on process plan 1, since the number of machine changes is four. The effect is minimum in process plan 3 where the number of machine change is one.

The cost comparison shows that the minimum cost process plan calculated without MHC is process plan 3, whereas, with cost calculations including MHC the minimum cost is of process plan 2.

CONCLUSION

In this research the important features of RMS

Fig. 6: Process plan 1 for ANC-101

OC seq.	OC1	OC 2	OC 5					OC8	OC7	OC4	OC 6		OC11		OC10	OC 3	OC 9			
Machine	M1	M1	M1					M4	M4	M4	M6		M6		M4	M3	M3			
Config.	1	1	4					1	2	2	1		1		1	1	1			
TE	E7	E7	E7					E6	E6	E6	E7		E7		E6	-	-			
PE	E1	E1	E1					E1	E1	E1	E1		E1		E1	E2	E2			
OP Seq.	1	2	5	6	7	8	9	6	7	8	10	11	19	20	12	4	14	15	16	17
TAD	Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	Z	Z	-Z	-Z	-A	-A	-A	-A
Tool used	6	6	7	7	3	9	10	7	3	9	1	5	9	10	6	6	6	3	9	10

ISSN 1023-862X - eISSN 2518-4571

Fig. 7: Process plan 2 for ANC-101

OC seq.	OC1	OC7	OC4	OC2	OC5					OC8	OC10	OC6		OC9				OC11		OC3
Machine	M1	M1	M1	M1	M1					M4	M4	M3		M3				M6		M6
Config.	1	2	2	1	4					1	1	1		1				1		1
TE	E7	E7	E7	E7	E7					E6	E6	E6		E6				-		-
PE	E2	E2	E2	E2	E2					E1	E1	E2		E2				E1		E1
OP Seq.	1	12	4	2	5	6	7	8	9	13	18	10	11	14	15	16	17	19	20	3
TAD	Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	X	-X	-Z	-Z	-A	-A	-A	-A	Z	Z	Z
Tool used	6	6	6	6	7	7	3	9	10	6	6	1	5	6	3	9	10	9	10	2

Fig. 8: Process plan 3 for ANC-101

OC seq.	OC1	OC2	OC4	OC3	OC5					OC 6		OC7	OC11		OC8	OC10	OC9			
Machine	M1	M1	M1	M1	M1					M1		M1	M1		M5	M5	M5			
Config.	1	1	2	1	4					1		2	1		1	1	1			
TE	E7	E7	E7	E7	E7					E7		E7	E7		-	-	-			
PE	E2	E2	E2	E2	E2					E2		E2	E2		E1	E1	E1			
OP Seq.	1	2	4	3	5	6	7	8	9	10	11	12	19	20	13	18	14	15	16	17
TAD	Z	-Z	-Z	Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	Z	Z	X	-X	-A	-A	-A	-A
Tool used	6	6	6	2	7	7	3	9	10	1	5	6	9	10	6	6	6	3	9	10

Fig. 9: Process plan 4 for ANC-101

OC seq.	OC1	OC4	OC7	OC2	OC5					OC8	OC10	OC6		OC9				OC3	OC11	
Machine	M4	M4	M4	M4	M4					M4	M4	M6		M3				M6	M6	
Config.	1	2	2	1	4					1	1	1		1				1	1	
TE	E6	E6	E6	E6	E6					E6	E6	E7		E6				-	-	
PE	E1	E1	E1	E1	E1					E1	E1	E1		E2				E1	E1	
OP Seq.	1	4	12	2	5	6	7	8	9	13	18	10	11	14	15	16	17	3	19	20
TAD	Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	X	-X	-Z	-Z	-A	-A	-A	-A	Z	Z	Z
Tool used	6	6	6	6	7	7	3	9	10	6	6	1	5	6	3	9	10	2	9	10

Fig. 10: Process plan 5for ANC-101

OC seq.	OC1	OC 4	OC 7	OC 2	OC 5					OC 6	OC 3	OC 11		OC 8	OC 10				OC 9	
Machine	M1	M1	M1	M1	M1					M1	M1	M1		M4	M4				M3	
Config.	1	2	2	1	4					1	1	1		1	1				1	
TE	E6	E6	E6	E6	E6					E6	E6	E6		E7	E7				-	
PE	E2	E2	E2	E2	E2					E2	E2	E2		E1	E1				E2	
OP Seq.	1	12	4	2	5	6	7	8	9	13	18	10	11	3	14	15	16	17	19	20
TAD	Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	-Z	X	-X	-Z	-Z	-Z	-A	-A	-A	-A	Z	Z
Tool used	6	6	6	6	7	7	3	9	10	6	6	1	5	2	6	3	9	10	9	10

Table 8: Cost calculation for the five process plans

Costs Process Plans	MUC	TUC	TCC	SCC	MHC	Total cost
PP1	911	230	220	400	560	2321
PP2	861	230	220	300	390	2001
PP3	941	230	260	400	340	2171
PP4	923.5	230	220	300	380	2053.5
PP5	1011	319	240	300	510	2380

design, process plans & material handling system are identified and discussed. The lack of integration of machining requirements & MH system was sensed in current research. Hence, it was proposed that MHE be included in the process plan stage. In addition, various material handling costs are considered in the cost model. Various type of equipment is available for MH like transportation, positioning, unit load formation & storage/ retrieval equipment. Among these the equipment considered in this research are the transportation & positioning equipment according to the parameters considered in the process plan.

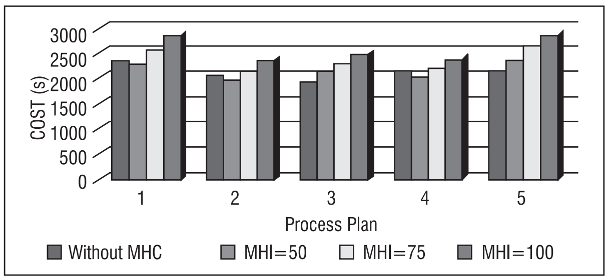


Fig. 12: Summary of Cost calculations for different values of MHI

The current work shows that MHE can be incorporated effectively in a machining setup to consider the cost involved in the machine change more accurately for each machine according to the MHE assigned to that machine to carry out the transportation & positioning tasks, as compared to previous models which considered machine change as a constant for each change. The inclusion of MHE cost gives an idea about the impact of these equipment on overall cost of manufacturing. The presented model will help in the decision-making process of allocating part to machines & also the allocation of MHE to each machine considered in the process plans with the aim of keeping the cost minimum.

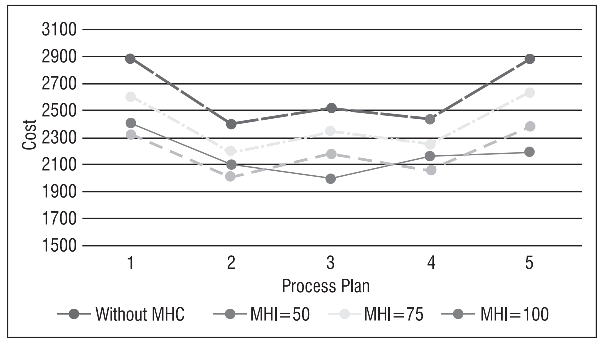


Fig. 13: Summary of Cost Comparison

An extension of the proposed work is the inclusion of material handling sub-operations such as orientation change when considering the MHE selection. This will lead to a replacement of the setup change cost which is treated as a constant for every TAD change. Other MH equipment such as unit load formation & storage/ retrieval equipment and their relevant operations can also be considered a part of the process plan & cost model.

Another future aspect of this work is the optimization of the process plans using evolutionary algorithms like GA, SA etc., for the selection of optimal process plans from a large option of randomly generated feasible process plans using cost. Another optimization criterion that could be set for this work can be the optimization of the material handling equipment selection based on compatibility at the process plan generation stage to ensure the selection of the best suitable MHE for a machine.

REFERENCES

1. *Azab, A., and ElMaraghy, H. A., (2009),“Reconfigurable Process Plans: A new approach to minimize change,” in Changeable and Reconfigurable Manufacturing Systems, Windsor, Springer-Verlag London Limited, pp. 179-194.*

2. *Koren, Y., (2006), "General RMS Characteristics. Comparison with Dedicated and Flexible Systems", in Reconfigurable Manufacturing Systems and Transformable Factories, pp. 27-45.*

3. *Li, W. D., Ong, S., and Nee, Y., (2002), "Hybrid genetic algorithm and simulated annealing approach for the optimization of process plans for prismatic parts", International Journal of Production Research, Vol. 40 (8), pp. 1899-1922. DOI: //doi.org/10.1080/00207540110119991.*

4. *Ling, C., Yip-Hoi, D., and Koren, Y., (2000), "Operation clustering in process planning for reconfigurable machining system design", Japan-USA Flexible Automation Conference, Ann Arbor.*

5. *M. G. Kay, Material Handling Equipment, 2012.*

6. *Ong S. K., and N. A. Y. C., (2002), ""Hybrid GA and SA dynamic set-up planning optimization," International Journal of Production Research, Vol. 40 (18), pp. 4697-4719. DOI: https://doi.org/10.1080/00207540210155864.*

7. *Paulo, J., Lashkar, R. S., Dutta, S.P., (2002), "Operation allocation and materials-handling system selection in a flexible manufacturing system: A sequential modelling approach," International Journal of Production Research, Vol. 40 (1), pp. 7-35. Doi: https://doi.org/10.1080/00207540110073028.*

8. *Shabaka, A. I., and Elmaraghy, H. A., (2007), "Generation of machine configurations based on product features", International Journal of Computer Integrated Manufacturing, Vol. 20(4), pp. 355-369. DOI: https://doi.org/10.1080/09511920600740627.*

9. *Shabaka, A. I., and ElMaraghy, H., (2008), "A model for generating optimal process plans in RMS", International Journal of Computer Integrated Manufacturing, Vol. 21 (2), pp. 180-19. DOI: https://doi.org/10.1080/09511920701607741.*

10. *Sujono, S., and L. Lashkari, (2017), "A multi-objective model of operation allocation & material handling system selection in FMS design", International Journal of Production Economics, Vol. 105, pp. 116-133 https://doi.org/10.1016/j.ijpe.2005.07.007.*

11. *Zhang, F., Zhang, Y., and Nee, A. Y. C., (1997), "Using Genetic Algorithms in Process Planning for Job Shop Machining", IEEE Transactions on Evolutionary Computation, Vol. 1 (4). DOI: 10.1109/4235.687888.*