Optimization of Process Plans for Manufacturing Technique using TLBO Algorithm

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Abstract- *Computer Aided Process Planning (CAPP) system is an important activity in the production industry to generate processing plans that contains the required details of machining operations, machining inputs (speeds, feeds and depth of cuts), machines, machine setups, cutting tools and accessories for producing a product as per given part details. In this context, to produce the optimum process plans, one of the AI based meta heuristic algorithm is used i.e., Teaching–Learning Based Optimization (TLBO) to solve the process planning problem to minimize machining time and operation sequence cost based on the natural phenomenon.*

Keywords- CAPP, Optimized solution, TLBO, process plans, Learner phase, machining inputs and setups.

I. INTRODUCTION

Computer aided Process planning (CAPP) deals with the selection of the machining operations sequence as per given drawing and determination of conditions to produce the part. It includes the design data, selection of machining processes, selection of machine tools, sequence of operations, setups, processing times and related costs. It explores operational details such as: sequence of operations, speeds, feeds, depths of cut, material removal rates, and job routes. Required inputs to the planning scheme include: geometric features, dimensional sizes, tolerances and work materials. These inputs are analyzed and evaluated in order to select an appropriate operations sequence based upon available machinery and workstations. Therefore the generation of consistent and accurate process plans requires the establishment and maintenance of standard databases and the implementation of an effective and efficient Artificial Intelligence (AI) heuristic algorithms like Genetic algorithm (GA), Simulated Annealing(SA), Ant Colony Optimization (ACO) and TLBO algorithm are used to solve these problems.

II. LITERATURE REVIEW

Since last three decades many evolutionary and heuristic algorithms have been applied to process planning problems. Usher and Sharma (1994) mentioned that several feasibility constraints which affects the sequencing of the machining operations. These constraints are processed sequentially based on the precedence relations of the design features. Usher and Bowden (1996) proposed an application of a genetic algorithm (GA) for finding near-optimal solutions. In 2002 Li et al. developed a hybrid GA and SA approach to solve these problems for prismatic parts. Gopal Krishna and Mallikarjuna Rao (2006) and Sreeramulu et al. (2012) presenteda developed meta-heuristic Ant Colony Optimization algorithm (ACO) as a global search technique for the quick identification of the operations sequence. Recently, TLBO is a newly developed algorithm introduced by Rao et al.(2011) based on the natural phenomena of teaching and learning process like in a classroom. Therefore it does not require any specific constraint process parameters. And also they (2013) proposed to solve the job shop scheduling problems to minimize the make span using TLBO algorithm. All the evolutionary algorithms require common controlling parameters like population size, number of generations etc. In addition to these common parameters, they may require own algorithm-specific parameters. For example GA contains mutation and cross over rate, PSO uses inertia weight.

III. TEACHING-LEARNING-BASED OPTIMIZATION ALGORITHM

In TLBO Algorithm teacher and learners are the two vital components. This describes two basic modes of the learning, through teacher (known as teacher phase) and interacting with the other learners (known as learner phase). Teacher is usually considered as a highly learned person who trains learners so that they can have better results in terms of their marks or grades. Moreover, learners also learn from the interaction among themselves which also helps in improving their results. TLBO is population based method. In this optimization algorithm a group of learners is considered as population and different design variables are considered as different subjects offered to the learners and learners' result is analogous to the fitness value of the optimization problem. In the entire population the best solution is considered as the teacher. TLBO algorithm mainly working of two phases, namely teacher phase and learner phase.

Teacher Phase

Teacher phase is the first phase of TLBO algorithm. In this teacher phase will try to improve mean of class. A good teacher is one who brings his or her learners up to his or her level in terms of knowledge. But in practice this is not possible and a teacher can only move the mean of a class up to some extent depending on the capability of the class. This follows a random process depending on many factors. Generate the random population according to the population size and number of generations [6].

Calculate the mean of the population, which will give the mean for the particular subject as M, P = [m1, m2, .mP]. The best solution will act as a teacher for that iteration X teacher = Xf(X) = min. The teacher will try to shift the mean from MP towards X teacher which will act as a new mean for the iteration. So, M new, P =X teacher P.

The difference between two means is expressed as

Difference P = ri (M new, P–TFMP) ……………… (1)
Where, ri is the random number in the range [0, 1], the value of Teaching Factor (TF) is considered 1 or 2. The obtained difference is added to the current solution to update its values using X new, P = X old, P + Difference P…………. (2)
Accept X new if it gives better function value.

Learner Phase

A learner interacts randomly with other learners for enhancing his or her knowledge [4]. Randomly select two learners Xi and Xj.
X'new, P= Xold,P+ ri(Xi-Xj) if f (Xi) < f (Xj)
X'new, P= Xold,P+ ri(Xj- Xi) if f (Xi) >f (Xj)

III. PROCESS PLANNING METHODOLOGY

In this algorithm the operation sequences are considered as learners and operations acts as subjects. The operation sequences are generated randomly according to the procedure of the algorithm. Calculate the time and cost for the generated sequences and identify the best teacher. In teacher phase update the solutions (from equa 2) and again calculate the time and cost. The flow chart of the TLBO Algorithm is as shown in figure 3.

The operation sequences are generated to develop a feasible and optimal sequence of operations for a part based on the technical requirements, including part specifications in the design, the given manufacturing resources, and certain objectives related to cost or time. The following formulas are used to calculate total time and manufacturing costs [8].

1. Machine cost (MC), MC is the total costs of the machines used in a process plan and it can be computed as:

   $$MC = \sum_{i=1}^{n}\left(Machine\left[Oper[i].Mac\_id\right].Cost * machining\ time\ of\ Oper[i]\right)$$

   Where Oper (i) = operation I, MCI is the machine cost index for the machine and Mac-id is the machine used for the operations.

2. Tool cost (TC), TC is the total costs of the cutting tools used in a process plan and it can be computed as :

   $$TC = \sum_{i=1}^{n}\left(Tool\left[OPer\left[i\right].Tool\_id\right].Cost * machining\ time\ of\ Oper\left[i\right]\right)$$

   Where TCI is the tool cost index for the tool and Tool-id is the tool used for the operation.

3. Number of set-up changes (NSC), the number of set-ups (NS) and the set-up cost (SC).

   $$NSC = \sum_{i=1}^{n-1}\Omega\left(\Omega_1\left(Oper\left[i\right].Mac\_id, Oper\left[i+1\right].Mac\_id\right)\Omega_1\left(Oper\left[i\right].TAD\_id, Oper\left[i+1\right].TAD\_id\right)\right)$$

   The correspondence NS and SC can be computed as:
   NS = 1+NSC

   $$SC = \sum_{i=1}^{NS} SCI \text{ , Where } \Omega_1\left(X,Y\right) = \begin{cases}1 & X \neq Y\\ 0 & X = Y\end{cases}, \quad \Omega_2\left(X,Y\right) = \begin{cases}1 & X = Y = 0\\ 0 & otherwise\end{cases}$$

   And SCI is the set – up cost index.

4. Number of Machine Changes (NMC) and Machine Change Cost (MCC), NMC and MCC can be computed as:

$$\sum_{i=1}^{n-1} \Omega 1(Oper[i]Max_{id}, Oper[i+1]Mac\_$$

NMC = $\sum_{i=1}^{n-1} \Omega_1 (Oper[i].Max\_id, Oper[i+1].Mac\_id)$

MCC = $\sum_{i=1}^{NMC} MCCI$

Where MCCI is the machine change cost index.

5. Number of Tool Changes (NTC) and Tool Change Cost (TCC) are computed as:

NTC= $\sum_{i=1}^{n-1} \Omega_2 (\Omega_1 (Oper[i].Mac\_id, Oper[i+1].Mac\_id), \Omega_1 (Oper[i].Tool\_id, Oper[i+1].Tool\_id))$

TCC = $\sum_{i=1}^{NTC} TCCI$

Where TCCI is the tool change cost index.

6. Total Weighted Cost (TWC)

TWC = $MC + TC + SC + MCC + TCC$

Case study: In this paper the process plans are generated for a prismatic part drawing based on manufacturing time and related cost. The part details,costs, precedence relations and number of generations are given as input to the algorithm. The output contains the process plans and their costs, machining times, setups. Part drawing details are shown in Fig.1 and Table.1 respectively.

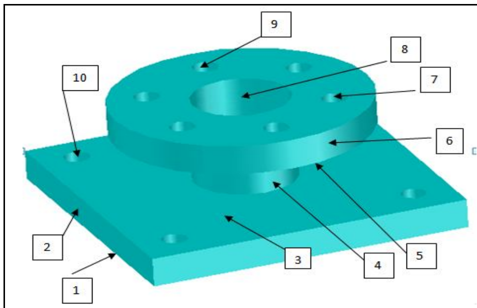

Fig.1. Part Drawing

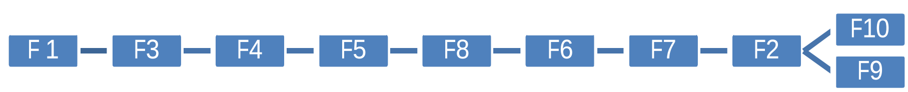

Fig.2. Precedence relation of the part drawing

Operations Information

Table.1 Operations information for part drawing

S.No	Feature ID	Name of Feature	Name of Operation	Operation ID	Dimensions (mm)
1	F_1	SQ Flange Bottom Surface	Milling	1	L=100,W=100,H=2
2	F_2	Edge (4 Sides)	Face Milling	2	L=100, w=15,H=1
			Face Milling	3	L=100, w=15 H=1
			Face Milling	4	L=100, w=15, H=1
			Face Milling	5	L=100, w=15, H=1
3	F_3	SQ Flange Top face	Top face Turning	6	L=100,W=100
4	F_4	Hub	Turning	7	D= 51 ,L =40
5	F_5	Round flange Bottom face	Facing	8	D=80, Depth=1
6	F_6	Round flange	Turning	9	D=80, L=15
7	F_7	Round flange top face	facing	10	D=80, Depth=1
8	F_8	Through bore	Drilling	11	Dia=50, depth=60
9	F_9	Holes on Round Flange	Drilling	12	Dia=4,depth= 15
			Drilling	13	Dia=4,depth= 15
			Drilling	14	Dia=4,depth= 15
			Drilling	15	Dia=4,depth= 15
			Drilling	16	Dia=4,depth= 15
			Drilling	17	Dia=4,depth= 15
			Drilling		Dia=4,depth= 15
10	F_{10}	Holes on SQ Flange	Drilling	18	Dia=4,depth= 15
			Drilling	19	Dia=4,depth= 15
			Drilling	20	Dia=4,depth= 15
			Drilling	21	Dia=4,depth= 15

The precedence relations for the part drawing are shown in Fig.2. These precedence relations are generated according to some standard rules. However, the user is allowed to choose the precedence relations according to requirements and available resources.

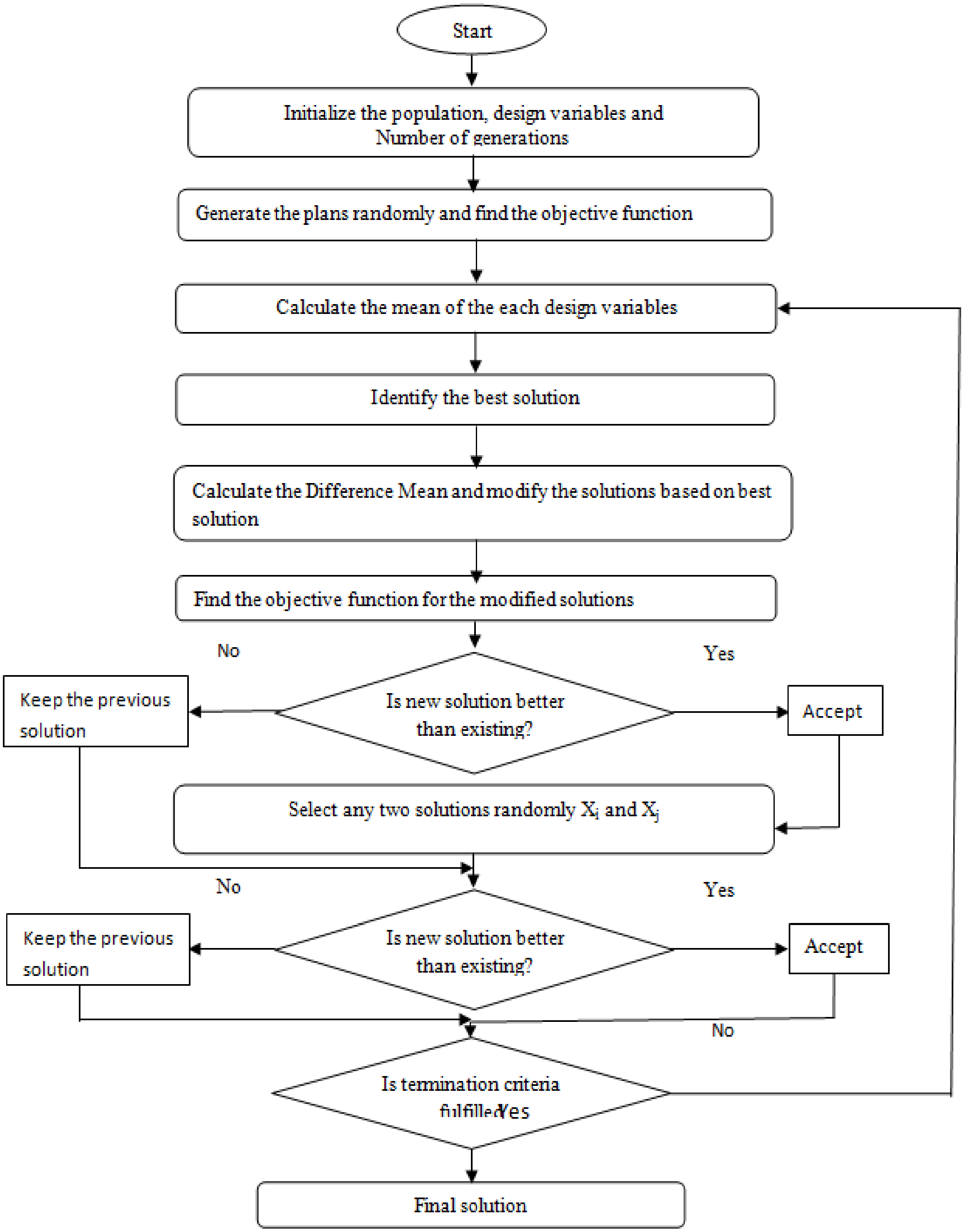

Fig.3 Flow chart of the TLBO Algorithm

Table 2: Best two process plans for part drawing

CRITERIAN 1: MINIMUM COST

OPERATION ID	1	6	7	8	11	9	10	2	3	4	5	12	13	14	17	16	15	18	19	20	21
OPERATION TYPE	7	4	13	4	3	13	4	7	7	7	7	3	3	3	3	3	3	3	3	3	3
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCATED	4	8	8	7	7	9	3	10	10	10	4	9	9	3	3	4	9	9	4	4	7
TOOL ALLOCATED	9	16	15	15	7	15	15	12	11	11	10	4	5	5	5	6	7	7	7	4	4
SET UP ALLOCATED	6	6	6	6	6	6	6	6	6	2	2	6	1	1	1	1	1	1	1	1	6

COST	595.21
TOTAL TIME	457.5
NO OF SETUPCHANGES	5
NO. OFTOOLCHANGES	13
NO OF M/C CHANGES	13
RAWMATERIALCOST	0.759

Total cost = 595.999

CRITERIAN 2: MINIMUM TIME

OPERATION ID	1	6	7	8	11	9	10	2	3	4	5	12	16	14	15	13	17	18	19	20	21
OPERATION TYPE	7	4	13	4	3	13	4	7	7	7	7	3	3	3	3	3	3	3	3	3	3
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCATED	10	8	7	3	4	3	3	10	10	10	4	8	8	7	7	8	8	8	10	10	4
TOOL ALLOCATED	9	15	15	15	4	16	16	9	9	9	12	5	5	7	7	6	6	5	6	6	4
SET UP ALLOCATED	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	6	1	6	6	6	6

COST	606.05
TOTAL TIME	427.5
NO OF SETUPCHANGES	5
NO. OFTOOLCHANGES	12
NO OF M/C CHANGES	13
RAWMATERIALCOST	0.759

Total cost = 606.839

Table.3: Alternative five process plans for part drawing

Part No	1

PLAN 1

Operation ID	1	6	7	8	11	9	10	2	3	4	5	12	16	14	15	13	17	18	19	20	21
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCA	10	8	7	3	4	3	3	10	10	10	4	8	8	7	7	8	8	8	10	10	4
TOOL ALLOCATED	9	15	15	15	4	16	16	9	9	9	12	5	5	7	7	6	6	5	6	6	4
SET UP ALLOCATE	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	6	1	6	6	6	6
OPERATION TIME	11.11	11.11	4.44	4.44	200.04	0.83	4.44	5.55	5.55	5.55	5.55	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

PLAN 2

Operation ID	1	6	7	8	11	9	10	2	3	4	5	12	13	14	17	16	15	18	19	20	21
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCA	4	8	8	7	7	9	3	10	10	10	4	9	9	3	3	4	9	9	4	4	7
TOOL ALLOCATED	9	16	15	15	7	15	15	12	11	11	10	4	5	5	5	6	7	7	7	4	4
SET UP ALLOCATE	6	6	6	6	6	6	6	6	6	2	2	6	1	1	1	1	1	1	1	1	6
OPERATION TIME	11.11	11.11	4.44	4.44	200.04	0.83	4.44	5.55	5.55	5.55	5.55	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

PLAN 3

Operation ID	1	6	7	8	11	9	10	2	3	4	5	12	13	14	15	17	16	18	19	20	21
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCA	10	8	8	9	9	3	3	10	10	4	4	10	10	4	10	8	9	8	8	8	8
TOOL ALLOCATED	9	16	16	16	5	16	15	9	9	9	11	7	4	7	6	5	5	5	5	6	6
SET UP ALLOCATE	6	6	6	5	6	6	6	6	2	6	6	1	1	1	6	6	1	1	1	1	1
OPERATION TIME	11.11	11.11	4.44	4.44	200.04	0.83	4.44	5.55	5.55	5.55	5.55	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

PLAN 4

Operation ID	1	6	7	8	11	9	10	2	3	5	4	12	13	14	15	16	17	18	19	20	21
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCA	4	9	9	3	4	9	9	4	4	4	10	8	8	9	10	9	9	4	8	3	8
TOOL ALLOCATED	10	15	16	16	6	16	16	12	9	11	11	4	7	7	6	6	4	6	5	5	6
SET UP ALLOCATE	6	6	6	6	6	6	6	6	6	6	6	6	1	6	6	6	6	6	6	1	6
OPERATION TIME	11.11	11.11	4.44	4.44	200.04	0.83	4.44	5.55	5.55	5.55	5.55	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

PLAN 5

Operation ID	1	6	7	8	11	9	10	2	3	4	5	12	13	16	15	14	17	18	19	20	21
OPERATION NAME	Milling	face Turning	Turning	Face Turning	Drilling	Turning	Face Turning	Milling	Milling	Milling	Milling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling	Drilling
MACHINE ALLOCA	4	3	7	3	9	3	3	10	10	10	10	10	10	10	10	7	4	4	8	8	4
TOOL ALLOCATED	11	16	15	15	5	16	15	11	9	9	10	7	5	5	6	7	7	7	5	4	6
SET UP ALLOCATE	2	5	5	5	6	5	6	6	6	6	6	1	1	1	1	1	1	1	6	6	6
OPERATION TIME	11.11	11.11	4.44	4.44	200.04	0.83	4.44	5.55	5.55	5.55	5.55	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5

IV. CONCLUSION

In this paper TLBO algorithm is used for solving process planning problem based on sequencing of machine operations. The problem modeled with manufacturing time and associated cost as the objectives. The better results are obtained with TLBO algorithm.

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