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Research Article

Application and validation of NSGA-II for designing batch production in mass customised steel industry

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Abstract:

In recent pandemic situation the work orders from various customers are not stable due to the fact that the money flow is not happening as it was earlier. The work is based on unstable demand from customers of mass customized medium scale steel products manufacturing and leading exporters of precision components such as guide bush, steel collet, and feed finger. The industry considered for this work located in Coimbatore, South India follows a batch production system. Due to uncertainty in today's market the industry is unable to deliver the orders within the due date. Poor production planning is found out to be one of the reasons for not being able to keep up to the deadlines. The Non Dominated Sorting Genetic Algorithm (NSGA II) is applied to produce a set of solutions with makespan and tardiness cost. Then the Analytical Hierarchy Process (AHP) has been used to validate the results obtained.

1. Introduction

The growing competition in the markets demands the manufacturing companies to maintain a high throughput rate and avoid any delays in the deliveries to the customer. Throughput of a system may be affected by various factors such as production scheduling, bottlenecks, production visibility, Non Value added activities, material transportation, machine layout, rejections etc. Hence in order to improve the throughput of a system, it is important to improve all these area. Production scheduling problem has been an area of focus by many researchers over the years. It plays a very important role in smooth functioning of the production system and reducing the total manufacturing time. Hence, makespan without a delay in the delivery of the orders can be used to reduce the throughput time of the system.

The data were collected from a medium scale steel industry in Coimbatore district of South India which manufactures various types of precision tools such as Steel Collet, Guide Bush, and Feed Finger etc. The industry is catering to the needs of thousands of end customers in the field of Automobile, Defence, Textile, Space, Electronics, Watches, Medical and other allied industries. They use batch production system for manufacturing. The manufacturing processes include machining operations such as Turning, Milling, and Grinding etc. The manufacturing process for one of the products, steel collet is as follows: First, the product undergoes turning operation to obtain the required diameter. Then face milling is performed. Then the component is hardened and tempered to obtain required hardness. Then Brazing operation (using acetylene torch) is performed. Then OD grinding is performed for smooth outer surface, followed by slitting operation, ID grinding and surface polishing. After all manufacturing processes are completed the components are inspected and packed. The rejected parts are sent for reprocessing. The manufacturing processes for other components are the same except for few variations. The NSGA II Algorithm is used to search for a solution. Then the analysis has been carriedout using Analytical Hirarchy Process and validation is done.

2. Literature Review

Pisut Pongchairerk [12] developed a two level metaheuristic algorithm for job shop scheduling. It includes an upper level algorithm and lower level algorithm. The lower level algorithm is a population based search for an optimal schedule and the upper level algorithm controls the parameters of the lower level algorithm. Yi Feng et al[14] used Grasshopper algorithm for Flexible Job Shop Scheduling. This algorithm works towards minimizing the makespan of all the jobs. Pandian R et al [11] used simple heuristics for creating flexible job shop schedules in a mass customized industry. Ming Huang et al (2020) used Ant Colony algorithm for single objective job shop scheduling with the objective of minimizing the maximum completion time of all the jobs. John Holland (1970) developed Genetic Algorithm inspired by Charles Darwin theory. This algorithm has been applied in the engineering field for optimization problems. This algorithm was developed by Srinivas and Deb [13] into Non Dominated Sorting Genetic Algorithm (NSGA) in 1995. In 2002 elitist NSGA II algorithm was developed by Kalyanmoy Deb et al [6]to overcome the disadvantages of the previous algorithms such as computational complexities and non-elitism approach. P. Mohapatra et al (2014) used NSGA II algorithm for Job shop scheduling they used the algorithm to minimize the makespan and operational cost and maximize the machine utilization time. They also concluded that controlled elitist NSGA II algorithm outperformed NSGA II in terms of the objectives. Ali et al. [4] used NSGA II Algorithm and a hybrid cuckoo search algorithm to find a set of non-dominated solution for a multiobjective supply chain problem. The problem aims at minimizing total cost and total lead time. The results suggested an enhanced efficiency if NSGA II-Cuckoo algorithm. Mina Ebrahimiarjestan et al [5] used NSGA II algorithm to find decoupling points in supply chain network to minimize product delivery cos and time while maximizing customer satisfaction. Dalessandro Soares Vianna et al [2] created a method to create production schedule for a Brazilian Garments company with minimum production time, minimum downtime and maximum utilization of internal production centres. They used NSGA II algorithm to obtain a set of solutions and then selected a single solution from this set of solution using weighted sum method. Vladimir Rankovic et al.[1] used Genetic Algorithm for multi objective supplier selection problem. He made a comparison between Weighted Sum Method and Strength Pareto Evolutionary Algorithm (SPEA). The first approach gives only one solution whereas in the second approach there are a set of solutions to choose from. But the drawback of the second approach is that the decision maker cannot have influence on the importance of any objective. Wilfried Jakob et al [3] presented a classification of application scenarios and a comparison of pareto optimal method with an extended weighted sum method known as cascaded weighted sum and discussed its strengths and weaknesses. Thus we can see that the NSGA II algorithm is an effective method for multi objective optimization and applying this to minimize makes pan and cost would help the company to increase the throughput rate while delivering all the orders on time.

3. Process flow in a customized steel parts manufacturing plant

The manufacturing company under study is a major exporter of precision components located in Co-imbatore, Tamilnadu, India.

There are around hundred orders with different batch size to be fulfilled in a month (for example some of the parts are given in Table 1). The company is facing difficulties in achieving the deadlines for delivering orders as per the customer requirements due to change in demand and less throughput rate of manufacturing in the company. It has been found that the production scheduling is inadequate and the company finds it difficult to meet the customer duetime. The NSGA II algorithm is one of the meta heuristic algorithms to search for the better solutions efficiently. And so the algorithm is used in this study.

Table 1. *Parts with batch size.*

S. No	Parts Name	Batch size
1	SC	60
2	SCV	30
3	GB	40
4	FF	60
5	SCV	30
6	SC	30
7	BFC	55
8	GB	34
9	GB	60
10	FF(45)	45

3.1 Methodology

NSGA II is a multi-objective evolutionary algorithm. An advantage of this algorithm is that it provides a set of solutions rather than a single solution. NSGA-II generates offspring by using a crossover and mutation and then selects the next generation according to non-dominated-sorting comparison. NSGA II can be applied effectively to manufacturing system. It can be used in production planning problems with multiple objectives. It has also been applied in handling the uncertainties in demand and planning the production to increase company's profit. In this paper NSGAII algorithm has been used as given in the flow chart as shown in in Fig 1 to make a production schedule such that the makespan and tardiness cost are appropriate.
The following are the two objective functions that are used to make a model with NSGA II.
Minimize

$$Z_1 = Max\ (st_{ij} + pt_{ij}) \quad (1)$$

Where
stij = process start time of job i in machine j
ptij = process time of job i in machine j

Minimize

$$Z_2 = \sum_{i=1}^{n} t_i * c_i \quad (2)$$

Where
ti is the tardiness of job i
ci is the tardiness cost of job i
These equations are considered as fitness functions with the real time data collected from the steel industry in Coimbatore, South India as shown in Table 2.

4. Application of NSGA II with a case study in steel industry

The following Table 2 provides the input data that were collected from the steel industry located at Coimbatore India. They are the suppliers of various auto industries. Due to varying demand in the steel parts as mentioned below are manufactured with varied batch sizes show with in the brackets next to the parts. Each column provides the processing time taken for the respective operations (noted as machines).
Algorithm steps
STEP 1: A random population of job sequence is to be created.
The random population is created as shown in Table.3. In this study it was considered to have population size as 10
STEP 2: Fitness values are foundout (makespan and tardiness cost are calculated) using the equations and 2.
STEP 3: Partially mapped crossover(PMX) is performed with a probability of 0.5 and fitness values are calculated. proceed to STEP 4. The Crossover and Mutation operations are shown in Fig 2 and Fig 3 respectively.

Table 2. *Estimation results of stochastic frontier gravity model.*

	Machines													
Jobs	S.No	Parts	T	M	F	B	OG	G	WC	IG	PP	SF	QC	PA
	1.	SC	610	610	500	1210	910	610	0	610	0	1210	310	610
	2.	SCV	310	310	500	0	460	310	1440	310	0	610	160	510
	3.	GB	0	410	500	810	610	0	0	410	410	210	210	410
	4.	FF	610	610	500	0	0	610	0	610	0	1210	310	610
	5.	SCV	310	310	500	0	460	310	1440	310	0	610	160	310
	6.	SC	310	310	500	610	460	310	0	310	0	610	160	310
	7.	BFC	560	560	500	0	0	560	0	560	0	1110	285	560
	8.	GB	0	110	500	210	160	0	0	110	110	60	60	110
	9.	GB	0	210	500	410	330	213	0	210	210	110	110	210
	10.	FF	450	450	500	0	0	450	0	450	0	910	230	450

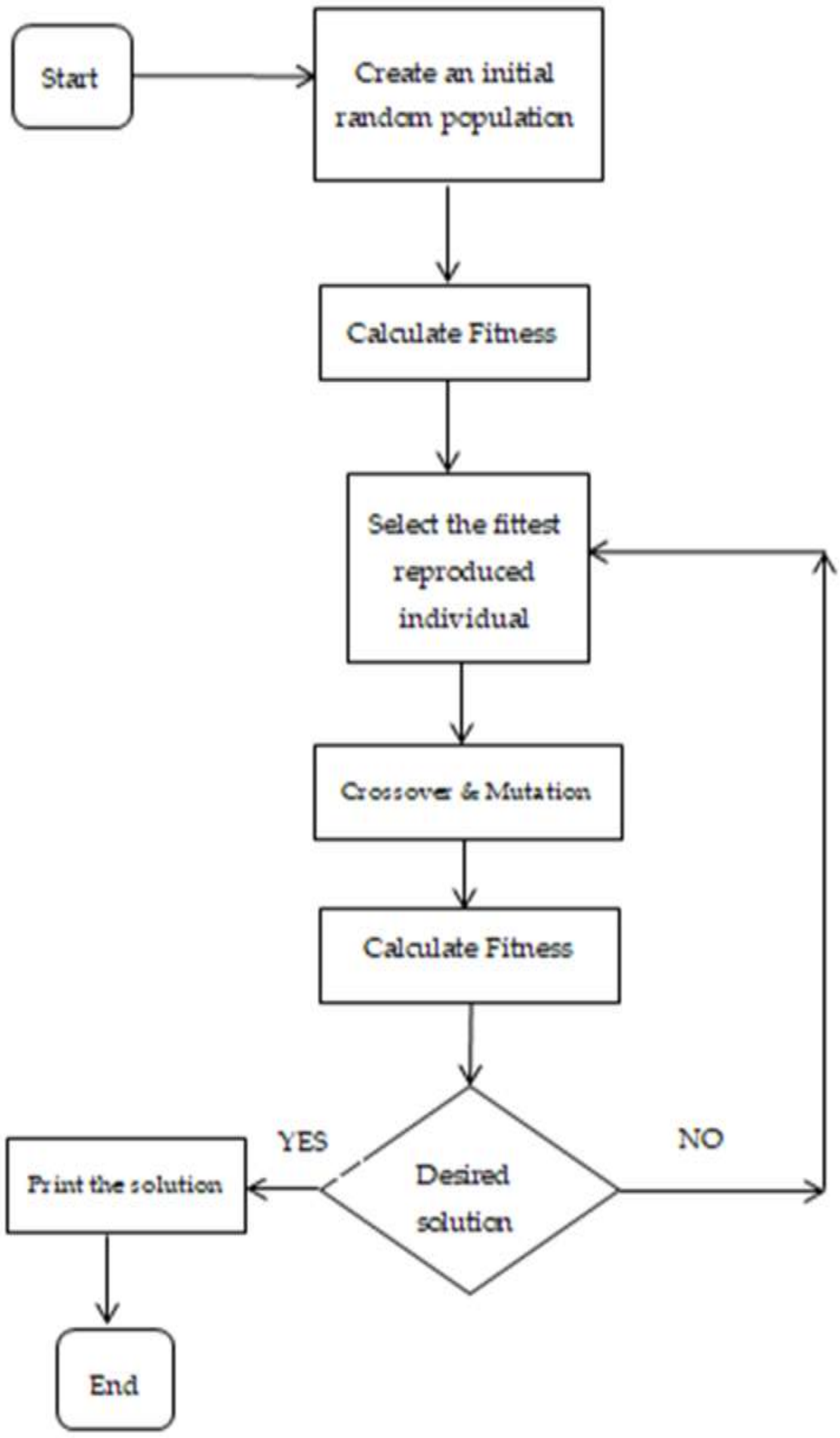

Figure 1. *Flow chart of NSGA II*

Table 3. *Estimation results of stochastic frontier gravity model.*

S.No	Sequence of Job	Z1	Z2
1	[9, 3, 8, 6, 7, 4, 5, 2, 10, 1]	10630	1268000
2	[10, 2, 5, 3, 6, 7, 1, 4, 8, 9]	9820	2645000
3	[10, 1, 3, 2, 8, 7, 4, 9, 6, 5]	9700	2001500

4	[2, 3, 10, 9, 5, 4, 8, 6, 7, 1]	11040	1212000
5	[7, 10, 2, 5, 3, 9, 1, 4, 6, 8]	10260	1246000
6	[7, 5, 2, 3, 8, 10, 1, 9, 6, 4]	10650	1513000
7	[5, 10, 8, 6, 3, 4, 1, 7, 9, 2]	9900	1871500
8	[3, 5, 8, 10, 1, 2, 7, 9, 6, 4]	10650	1672000
9	[1, 3, 5, 2, 9, 8, 10, 4, 6, 7]	10615	829000
10	[3, 4, 1, 10, 9, 2, 8, 5, 7, 6]	9535	642000

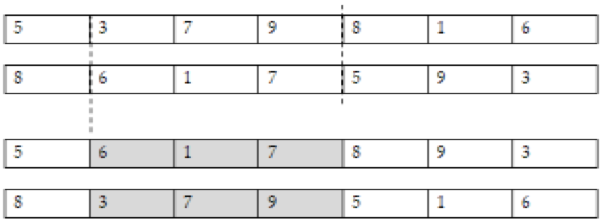

Figure 2. *Partially Mapped Crossover*

STEP 4: Mutation is performed with a probability of 0.1 as shown in Fig 2 and fitness values are calculated.

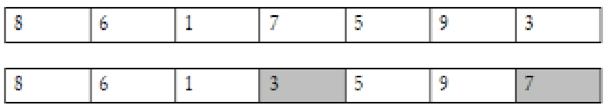

Figure 3. *Mutation*

STEP 5: The candidates for the next generation are selected using non dominated sorting

Table 4. *Estimation results of stochastic frontier gravity model.*

S.No	Sequence of Job	Z1	Z2
1	[3, 4, 1, 10, 9, 2, 8, 5, 7, 6]	9535	642000
2	[2, 3, 1, 10, 8, 7, 4, 9, 6, 5]	9280	1841000
3	[5, 3, 1, 10, 9, 8, 2, 4, 6, 7]	10145	294000
4	[2, 3, 10, 9, 5, 1, 8, 6, 7, 4]	10250	687000
5	[8, 5, 2, 3, 7, 10, 1, 9, 6, 4]	9650	724000
6	[10, 1, 3, 2, 8, 7, 4, 9, 6, 5]	9700	2001500
7	[1, 3, 5, 2, 9, 8, 10, 4, 6, 7]	10615	829000
8	[3, 4, 1, 8, 9, 2, 10, 5, 7, 6]	9745	918000
9	[5, 6, 8, 10, 1, 4, 3, 7, 9, 2]	9780	1895000
10	[3, 4, 5, 2, 9, 10, 8, 1, 7, 6]	10140	1021500

STEP 6: Repeat the steps from STEP 2 to STEP 6 till it reaches the optimal solution (or) specified genera-tion number. The preferred solution in this case is reached in 21st generations and shown in section 5, Table 5. Then the results obtained are considered for validation using AHP.

Analytical Hierarchy Process

The analytic hierarchy process (AHP) approach is one of the most commonly used decision-making procedures. It seeks to quantify the relative priority of a given set using an appropriate value scale. The AHP process begins by describing the alternatives that must be examined. It is one of the most advanced methodologies available in the field of management science and operations research. These choices could represent the various criteria against which solutions must be judged.After establishing a hierarchy of criteria the pairwise analysis is done. The weights of alternatives with regard to each criterion are computed using the method suggested by Saaty [17] . The weighted summation is then used to calculate the overall weights of the alternatives. The decision is usually made based on the viewpoint of the person who is intended to make the ultimate decision and analyse priorities.

5. Results and Validation using AHP

In the 21st iteration the values of makespan (Z1) and tardiness cost (Z2) as mentioned in Table 5 reflects the preferred solution by the industry based on the fluctuation in customers demand. It is inferred from Figure 4 and Table 5 the values for Z1 and Z2 are varying in random order. The Z1 and Z2 values are not proportionately varying as highlighted in Figure

4, so it is based on the decision maker to decide based the input from customers. Even though it is decided by the industry to choose the appropriate value, it is suggested to validated from bench mark method.

5.1 Validation of the model using AHP

The following weights are made from the values of

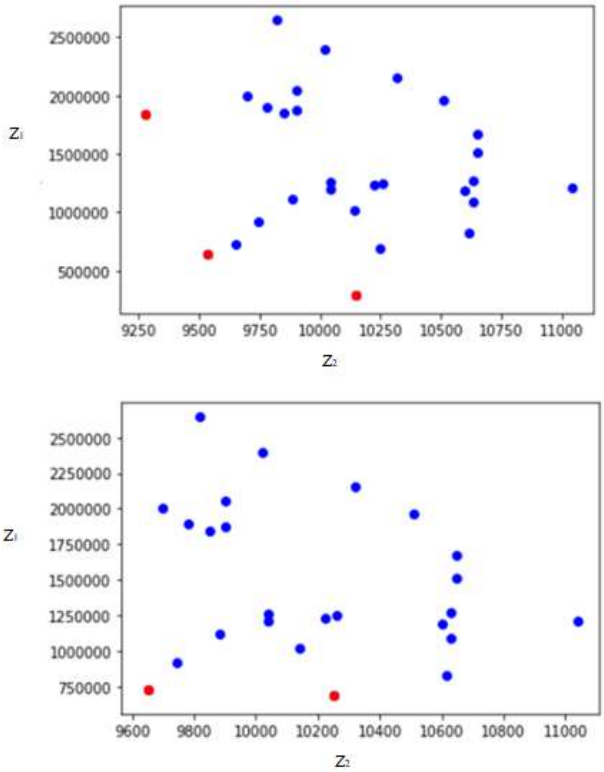

Figure 4. *Fitness values in NSGA II*

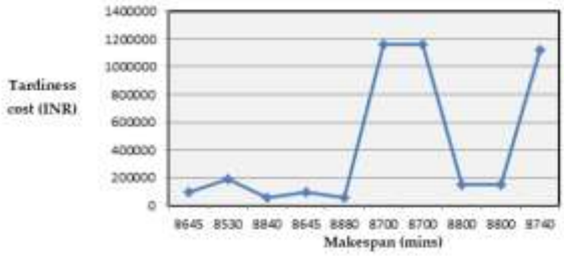

Figure 5. *Makespan (Z1) Vs Tardiness Cost (Z2) using NSGA*

Table 5. *Estimation results of stochastic frontier gravity model.*

S.No	Sequence of Job	Z_1 (min)	Z_2 (INR)
1	[9, 5, 1, 8, 10, 3, 4, 7, 2, 6]	8880	57000
2	[9, 5, 1, 3, 10, 7, 4, 2, 8, 6]	8840	57000
3	[9, 5, 1, 7, 10, 3, 4, 2, 8, 6]	8800	147000
4	[9, 2, 6, 10, 1, 7, 8, 4, 5, 3]	8740	1119000
5	[8, 2, 6, 10, 1, 7, 9, 4, 5, 3]	8700	1157500
6	[9, 5, 1, 3, 4, 7, 10, 2, 8, 6]	8645	93000
7	[9, 5, 1, 7, 4, 3, 10, 2, 8, 6]	8530	191000

the results shown in Table 5. With respect to standard AHP procedure given by [18]. The calculations are made based on the formulae used in this research article to arrive at final criteria weights as shown in consecutive Tables [6-8].

Table 6. *Makespan (Z1) PAIRWISE comparison*

	PZ_{11}	PZ_{12}	PZ_{13}	PZ_{14}	PZ_{15}	PZ_{16}	PZ_{17}
PZ_{11}	1	1	3	5	7	8	9
PZ_{12}	1	1	2	4	6	7	8
PZ_{13}	0.33333	0.5	1	3	5	6	7
PZ_{14}	0.20	0.25	0.33333	1	4	5	6
PZ_{15}	0.14286	0.16667	0.2	0.25	1	4	5
PZ_{16}	0.125	0.14286	0.16667	0.2	0.25	1	4
PZ_{17}	0.11111	0.125	0.14286	0.16667	0.2	0.25	1

Table 7. *Tardiness cost (Z2) PAIRWISE comparison*

	PZ_{21}	PZ_{22}	PZ_{23}	PZ_{24}	PZ_{25}	PZ_{26}	PZ_{27}
PZ_{21}	1	1	5	7	7	9	9
PZ_{22}	1	1	5	7	7	9	9
PZ_{23}	0.2	0.2	1	3	3	5	5
PZ_{24}	0.142857	0.142857	0.333333	1	2	4	4
PZ_{25}	0.142857	0.142857	0.333333	0.5	1	3	3
PZ_{26}	0.1111111	0.111111	0.2	0.25	0.333333	1	2
PZ_{27}	0.111111	0.111111	0.2	0.25	0.333333	0.5	1

Table 8. *Random Consistency Index*

Matrix Size	1	2	3	4	5	6	7	8	9	10
Random Consistency Index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 9. *Criteria weights*

S.No	Makespan Z_1		Tardiness cost Z_2	
	Criteria weight (CWZ_1)	Significance (%)	Criteria weight (CWZ_2)	Significance (%)
1	0.02172	2%	0.3455	35%
2	0.0385	4%	0.3455	35%
3	0.06352	6%	0.07582	8%
4	0.10713	11%	0.03147	3%
5	0.17402	17%	0.02487	2%
6	0.27476	27%	0.12056	12%
7	0.32036	32%	0.05628	6%

The following table is considered from Tatjana et al [18] for choosing random consistency index for the calculation of consistency ratio for both Z1 and Z2. In this work the chosen number is 7 for calculation purpose so the appropriate random index is 1.32. The criteria weights are calculated using the formula suggested by Saaty [19] and shown in Table 9. These criteria weight values are used to calculate the consistency ratio using the formula developed by Saaty [19] which must be less than 0.1.

6. Conclusions

The mass customized steel industry considered in this study that produces various steel parts for automobile industries are not able to meet the due date because of inappropriate production schedule. Using NSGA II, the results obtained are validated using AHP. The level of inconsistency is acceptable if Consistency Ratio is less than 0.1. Otherwise, there is a significant level of inconsistency, and the policy maker may need to reevaluate the aspects. In this study the consistency ratio for Z1 is 0.0965 and Z2 is 0.05721. So both fitness values obtained using NSGA II are acceptable within the range.
The batch sizes are varying due to instable demand in market changes. The batch sizes are considered during the data collection in the industry. It may be different for various periods. In future the factors like inventory cost, travel distance, setup time could be considered for making it more realistic research work.

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