Mehran University Research Journal of Engineering & Technology
Vol. 37, No. 3, 545-552 July 2018
p-ISSN: 0254-7821, e-ISSN: 2413-7219
DOI: 10.22581/muet1982.1803.09

Modified NEH Algorithm for Multi-Objective Sequencing in Mixed-Model Assembly Lines

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RECEIVED ON 10.05.2017 ACCEPTED ON 21.08.2018

ABSTRACT

Assembly lines are usually used for the mass production. The dawn of mass customization has forced the industries to shift to MMAL (Mixed-Model Assembly Lines). ALBP (Assembly Line Balancing Problem) and MSP (Model Sequencing Problem) are two major problems in MMAL. Sequencing of models is an important aspect of MMAL because improper sequencing can lead to the production loses. This paper dealt with the MSP in MMAL. A modified INEH (Intelligent Nawaz, Enscore, and Ham) algorithm was developed to solve multi-objective MSP. For this purpose, a MCDM (Multi-Criteria Decision Making) techniquewas integrated with NEH. A mathematical model was presented for three performance measures; Idle time, Make-span and Flow Time. A case study of pumps assembly line was conducted. Proposed INEH simultaneously optimized all performance measures (Flow Time= 123.47min, Make-Span= 156.95min and Idle Time=1.67 min) while the traditional NEH variants only optimized single performance measure and ignoring the others. Performance of the proposed algorithm was compared with traditional NEH algorithm and its variants using TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), a MCDM technique. Results showed that proposed INEH outperformed rest of the NEH algorithms as TOPSIS ranked INEH first with the relative closeness of 97.3% while the NEH variant for flow time is worse algorithm with the relative closeness of 2.8%.

Key Words: Assembly Lines, MixedModel, Nawaz, Enscore, and Ham Algorithm, Multi Objective Optimization.

1. INTRODUCTION

Assembly lines are being used for mass production, because of their advantages over other production systems in terms of cost and lead time. It has been distinguished into three classes. Most common class used in mass customization environment is MMAL [1]. There are two major problems in MMAL; ALBP and MSP. ALBP deals with the assigning of task to stations with the aim to optimize the cycle time, smoothness index and balance efficiency etc. while MSP deals with the determination of the order in which the product should be assembled which minimize/ optimize the flow time, cycle time and idle time etc. [2,3]. In this research, MMAL-SP has been discussed.

Research had been conducted on different aspects of MMAL-SP and one such aspect was objective functions.

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Shao et. al. [4] addressed the SPs in pull production systems which were composed of one mixed-model assembly line and one flexible fabrication flow line with limited intermediate buffers. They considered two objectives simultaneously: minimizing the total variation in parts consumption in the assembly line and minimizing the make-span in the fabrication line. They proposed multi-objective genetic algorithm and had proved that the proposed algorithm was more efficient in minimizing both objectives than existing multi-objective simulated annealing algorithm. Kucukkoc and Zhang [5] introduced a mixed-model parallel two-sided assembly line system based on the parallel two-sided assembly line. Object was to minimize the weighted idle time of the workstations. Ponnambalam et. al. [6], Guo et. al. [7], Saif et. al. [8], Muthiahand Rajkumar [9], Norozi et. al. [10], Tahriri et. al. [11], Tavakkoli et. al. [12] and Fattahi et. al. [13] minimized the flow time, make-span and idle time for MMALSP.It can be summarized from the above literature that flow time, make-span, lateness, idle and setup time are the important performance measure for MMAL-SP. Therefore, in this work MMAL-SP has been solved while minimizing the flow time, make-span, idle time and setup time. Besides objective functions, various optimization techniques were developed by researchers to optimize MMAL-SP's objectives.

Some of the recent researches on MMAL-SP's solution has been reviewed in the following lines. Fattahi et. al. [13] has solved the MMALSP with ant colony algorithms and heuristics of simulated annealing. Salehi et. al. [14] proposed simulated annealing algorithm to solve MMAL-SP. Ramalingam and Senthilkumar [15] proposed simulated annealing algorithm for level production scheduling. Rahimi-Vahed et. al. [16] proposed a hybrid multi-objective algorithm based on PSO (Particle Swarm Optimization) and TS (Tabu Search) to solve MMALSP. It was compared with three multi-objective algorithms. The results show that the proposed algorithm outperforms existing algorithms. Kucukkoc and Zhang [5] had proposed an agent-based ant colony optimization algorithm to solve the problem. Ponnambalam et. al. [6], Guo et. al. [7], Saif et. al. [8], Muthiah and Rajkumar [9], Norozi et. al. [10], Tahriri et. al. [11], and Tavakkoli et. al. [12] had proposed genetic algorithm to solve MMAL-SP. Beside meta-heuristic algorithms, researcher had also used constructive algorithms to solve MMAL-SP. The NEH algorithm had found to be one of the best constructive methods for the scheduling and sequencing, Jin et. al. [17]. Kalczynski and Kamburowski [18] and Liu et. al. [19] had proposed new techniques to increase the performance of NEH. NEH algorithm was proved to be best algorithm for make-span minimization problem. Rossi et. al. [20] had proved that NEH was the best constructive algorithm to minimize the make-span. Although it is not best algorithm for flow time and idle time minimization problems but still it provides significant results. NEH algorithm had been adopted by Framinan et. al. [21] to minimize the make-span, flow time and idle time separately. Wang et. al. [22] and Li et. al. [23] used NEH hybridization for flow time minimization while Liu et. al. [24] proved that NEH algorithm can be adopted for idle time minimization. It is acknowledged that NEH algorithm and its variants perform well for single objectives problem such as idle time, flow time and make-span, Arroyo and Armentano [25]. But they can also be used for multi-objective problems. To use NEH for multi-objective problems various methods had been introduced. Rauf et. al. [26] integrated the PROMTHEE technique with NEH algorithm for multi-objective optimization. Arroyo and Armentano [25] integrated Pareto Solution concept with NEH to solve multi-objective optimization problem. In that research, make-span and tardiness had been minimized simultaneously. One of the other methods is the use of MCDM techniques.

In this research, a modified INEH algorithm has been proposed. In which TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), a MCDM technique, has been integrated for decision making. In TOPSIS, distances to the positive and negative ideal solution are calculated instantaneously to determine the ranking order of all alternatives, [27]. Use of MCDM technique with the integration of NEH for multi-objective optimization is a novel approach. It provides the algorithm with required decision-making intelligence to solve multi-objective optimization problems effectively. Proposed INEH has been applied on a case study of pumps assembly lines in which three performance measures (flow time, make-span and idle time) were optimized simultaneously. Results of the proposed INEH algorithm has been compared with the existing NEH algorithms for flow time, make-span and idle time. For comparison purpose, a MCDM technique has been proposed.

2. MATHEMATICAL MODELING

First, Mathematical model of the performance measures has been developed. Development of constraints and underlying assumptions have been important part of the model. The MMAL under consideration, has been consisted of number of sequential stations which produce different models in an intermixed order. Each model has its own set of required tasks. Abbreviations used in this research are given below:

- i was the index used to represent a station, i=1,2,3, …, S
- j was the index used for a model, j=1,2,3, …, M
- C_j was the completion time of model m
- R_j was the arrival time of model m
- F_m was the flow time of model m
- M_s was the make-span of model m
- ID_m was the idle time of model m
- ID_i was the idle time at station i
- X_{ij} was a decision variable with value 1 only if model j is assigned to station i otherwise zero
- Y_{jr} was the decision variable with the value of 1 if model j is assigned in repetition r of MPS otherwise 0.

Performance measures have been illustrated in Equations (1-3).

$$Z_1 = \min\left(\sum_{j=1}^{M} C_j - R_j \right) \tag{1}$$

First performance measure for MMAL-SP was given is Equation (1) and was used to minimize the total flow time.

$$Z_2 = \min\left(\sum_{i=1}^{S} ID_i \right) \tag{2}$$

Second performance measure was expressed in Equation (2) and was important in minimizing the idle time.

$$Z_3 = \min\left\{ \max\left(C_j \right) \right\} \tag{3}$$

Third performance measure was given in Equation (3) and was used to minimize the make-span.

Subjective to

$$\sum_{i=1}^{S} X_{ij} = 1, \forall \{ j = 1,2,...,M \} \tag{4}$$

Equation (4) indicated that no more than one part can be processed on a single machine at a time. Each job could only be assigned to a single machine at a time.

$$\sum_{j=1}^{M} X_{ij} \geq 0, \forall \{ i = 1,2,..., S \} \tag{5}$$

Equation (5) insured that station can be idle. Following assumptions were used in this paper:

- Line was already balanced.
- The number of different models and their respected precedence diagram, process times were constant.

- Movement of the part from one station to other was asynchronous and its travel time was assumed to be zero.

3. CASE STUDY

A case study of pumps assembly line had been conducted to elaborate the proposed algorithm. There were five Models (A, B, C, D, E), which were required to be assembled on seven stations MMAL as shown in Fig. 1. Assembly line under consideration was asynchronous un-paced line. It means an operator starts to work on the next part as soon as it becomes available. Thus, the movement of parts are not coordinated. On completion of service the parts immediately move to the next machine or work station, if the space is available for it.

Twenty-four tasks are required to perform for the complete assembly of single model. These tasks were assigned to seven workstations using mixed-model assembly line balancing algorithms. Balancing of assembly line is out of the scope of this paper. So, the process time of each model at various stations was given in the Table 1.

The Company required to find out the sequence of model which simultaneously optimized three performance measure (flow time, make-span and idle time). Flow time is associated with the response of assembly line to the demand while make-span is used to increase the system throughput. So, minimization of one flow time leads to the maximization of make-span and vice versa. Same is the case with machine idle time as minimum idle time significantly increases the flow time and make-span. So, an INEH algorithm was proposed which simultaneously optimized the above mentioned conflicting performance measures.

4. IMPLEMENTATION OF INEH

NEH algorithm was applied for the sequencing of models in MMAL to minimize the flow time, make-span and idle time. As these were tradeoff/conflicting objectives so, it was necessary to find out the optimal solution which can optimize all the objectives. TOPSIS, a MCDM technique, was integrated into existing NEH algorithm for decision making. Steps involved in implementation of proposed INEH are described below along with the pumps assembly case study.

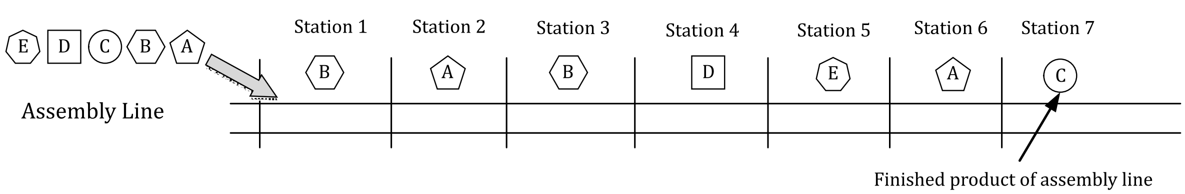

FIG. 1. DESCRIPTION OF MMAL

TABLE 1. PROCESS TIME OF MODELS ON RESPECTIVE WORK STATION

Model	Work Station-1 (min)	Work Station-2 (min)	Work Station-3 (min)	Work Station-4 (min)	Work Station-5 (min)	Work Station-6 (min)	Work Station-7 (min)	Total Time (min)
A	3.00	3.50	3.45	2..4	2.80	3.60	2.87	19.22
B	3.23	3.10	3.40	3.65	3.12	2.98	3.14	22.62
C	3.40	3.23	3.75	3.12	3.37	3.14	3.07	23.08
D	2.88	3.56	3.78	3.40	3.33	3.50	3.85	24.30
E	3.12	2.97	2.88	3.40	3.50	3.15	3.14	22.16

Step-1: Arranged the models in non-increasing order of total process time. Total process time for

Models A, B, C, D, E were 19.22, 22.62, 23.08, 24.30 and 22.16. Models arranged in non-increasing order as given: D-C-B-E-A.

Step-2: Pick first two models and order them to minimize the performance measure. As from the case study, first model D and C were ordered to minimize the performance measures. In this step, MCDM technique (TOPSIS) was integrated to obtain the better sequence for three performance measures. The notations used to perform TOPSIS are described below:

a	was the index for alternatives, a=1,2,3, …, A
c	was the index for criteria, c= 1,2, 3, …, C
PV_{ac}	was the value of performance measure from using algorithm a
Wa	was the weight of the performance measure
NPV_{ac}	was the normalized value of PVac
$WNPV_{ac}$	was the weighted normalized value of NPVac
IS^+, IS^-	were the set of positive ideal and negative ideal solutions respectively
SIS_a^+, SIS_a^-	were separation measures from IS+ (Positive Ideal Solution) andIS- (Negative Ideal Solutions), respectively
RC_a	were the relative closeness of the algorithm a

Steps for selection of sequence was briefly described in the line to follow:

First step of TOPSIS implementation was creation of decision matrix. It consisted of various available alternatives or choices, which are ranked against different objectives or criteria. As for this case study, various possible sequences and performance measures were alternatives and criteria respectively. Here decision matrix of alternatives x criteria has been created and given in Table 2. Performance measures was normalized using equation 6 and results were given in Table 3.

$$NPV_{ac} = \frac{PV_{ac}}{\sqrt{\sum_{a=1}^{A} PV_{ac}^2}} \tag{6}$$

Weights were assigned to performance measures. In current case study, equal weight of 0.33 were assigned to performance measures. Weighted normalized performance measures was calculated by Equation (7) and given in Table 4.

$$WNPV_{ac} = NPV_{ac} \text{ x } W_c \tag{7}$$

TABLE 2. DECISION MATRIX OF ALTERNATIVES AND CRITERIA

Model Sequences/Performance Measures	C-D	D-C
FT (min)	52.82	53.18
MS (min)	3.54	1.36
ID (min)	1.40	1.40

TABLE 3. NORMALIZED VALUE OF PERFORMANCE MEASURES

Model Sequences/Performance Measures	C-D	D-C
FT	0.7058	0.7084
MS	0.7047	0.7095
ID	0.9333	0.3591\

TABLE 4. WEIGHTED NORMALIZED VALUE OF PERFORMANCE MEASURES

Model Sequences/Performance Measures	C-D	D-C
FT	0.23644	0.23732
MS	0.23607	0.23769
ID	0.30799	0.11851

TABLE 5. POSITIVE IDEAL SOLUTION AND NEGATIVE IDEAL SOLUTION

PM/Solutions	FT	MS	ID
IS+	0.2364	0.2361	0.1185
IS-	0.2373	0.2377	0.3080

Set of IS+ and IS- were measured and given in Table 5.

For each sequence, separations from IS+ and IS- were measured using Equations (8-9) respectively. RC_a (Relative Closeness) to the ideal solution was measured for each sequence using Equation (10).

$$SIS_a^+ = \sqrt{\sum_{c=1}^{C}\left(WV_{ac} - WV_a^+\right)^2}, \forall a = 1,2,3,\ldots,A \quad (8)$$

$$SIS_a^- = \sqrt{\sum_{c=1}^{C}\left(WNPV_{ac} - WNPV_a^-\right)^2}, \forall a = 1,2,3,\ldots,A \quad (9)$$

$$RC_a = \frac{SIS_a^-}{\left(S_a^- + S_a^+\right)} \quad (10)$$

RC_a is the ratio of the distance from IS- and total distance. Larger the RC_a, better the sequence and sequence with maximum RC_a value was the best sequence. Separation from IS+, IS- and RC_a are given in Table 6. Sequences were ranked in descending order on the bases of RC_a value. From Table 6 sequence D-C was better for above mentioned performance measures than sequence C-D.

Step-3: Insert the m[th] model at the place which minimize the performance measure. Model-B had beeninserted in the sequence D-C to optimize the performance measures.

TABLE 6. POSITIVE SEPARATION, NEGATIVE SEPARATION AND RELATIVE CLOSENESS

Model Sequences/Criteria	C-D	D-C
SISa+	0.1895	0.0018
SISa-	0.0018	0.1895
RCa	0.0096	0.9904
Ranking	2	1

TOPSIS was used to select the best sequence. This step was repeated along with TOPSIS until all the models are sequenced. Sequence obtained from INEH is as given; D-E-C-B-A.

5. ANALYSIS OF RESULTS AND DISCUSSION

Problem was also solved by traditional NEH algorithm and its variants to minimize FT, MS and ID. Sequence obtained after applying the Modified NEH and NEH for FT, MS and ID were as given in Table 7.

It can be seen from Table 7 that NEH for make-span, only minimize the make-span (151.59 min) while ignoring the other performance measures (flow time = 121.60 and idle time = 12.76 min). While, NEH adoption for flow time provided minimum flow time (121.03 min) as compared to the rest of the algorithms but the values of make-span (151.59 min) and idle time (18.85 min) were not optimized. In the case of NEH adoption for Idle time, it optimized the idle time with the value of 1.58 min with the value of 123.84 and 157.26 min for flow time and make-span respectively. While the proposed INEH algorithm optimized all three performance measures with the values of 123.47, 156.95 and 1.67 min for flow time, make-span and idle time respectively. From the above discussion, it can be seen that flow time, make-span and idle time were tradeoff/conflicting performance measures. It was not possible to decide which algorithm perform better for all the performance measure without using any decision-making technique. It was imperative to use MCDM technique to determine which algorithm perform better for all three performance measures. In the literature Parthanadee and Buddhakulsomsiri [27] had used TOPSIS for the comparison of algorithms. So MCDM

TABLE 7. OPTIMIZED SEQUENCE OBTAINED FROM VARIOUS NEHS

Algorithms	Optimised Sequence	Flow Time (min)	Make-Span (min)	Idle Time (min)
INEH	D-E-C-B-A	123.47	156.95	1.67
NEH (Flow Time)	A-B-E-D-C	121.03	151.59	18.85
NEH (Idle Time)	D-E-B-C-A	123.84	157.26	1.58
NEH (Make-span)	E-A-B-C-D	121.60	151.51	12.76

TABLE 8. POSITIVE SEPARATION, NEGATIVE SEPARATION AND RELATIVE CLOSENESS OF ALGORITHMS

Model Sequences/Criteria	INEH	NEH (Flow Time)	NEH (Idle Time)	NEH (Make-Span)
SISa+	0.0067	0.2472	0.0105	0.1595
SISa-	0.2472	0.0072	0.2396	0.0879
RCa	0.97364	0.02848	0.95804	0.35523
Ranking	1	4	2	3

technique (TOPSIS) was used to select the best algorithm on the bases of flow time, make-span and idle time. Steps for implementation of TOPSIS had been already discussed. For simplification, only TOPSIS results are given in Table 8.

From the TOPSIS results, it can be seen that proposed INEH outperform rest of the algorithms while NEH (Idle time) was second best for above mentioned performance measures. It can be concluded from the above discussion that proposed INEH algorithm performed better as compared to the traditional NEH algorithm and its variants on the bases of flow time, idle time and make-span simultaneously. Proposed INEH algorithm can be used for sequencing and scheduling in automobile's manufacturing and assembly plants. It can significantly optimize their assembly lines to produce quality products in less amount of time which indeed reduce the assembly cost of the product. Proposed algorithm can also be used for multi-objective sequencing problems of flow shop and job shop. Proposed INEH is efficient algorithm for small scale multi-objective problem but for the complex and large-scale problems, it consumes more resource as it is based on the NEH algorithm which is constructive algorithm.

7. CONCLUSION

In this research, model sequencing problem in mixed-model assembly line has been discussed and a modified INEH algorithms has been proposed. In which, MCDM technique (TOPSIS) is integrated for the selection of various sequence alternatives. A mathematical model is also presented. INEH has been applied on the case study of pumps assembly line. Performance of the proposed algorithm is compared with the traditional NEH algorithm and its variants on the bases of flow time, idle time and make-span. TOPSIS is used for comparison. Results obtained from TOPSIS showed that INEH outperformed rest of the algorithms. It is recommended to use proposed INEH algorithm instead of traditional NEH algorithm while solving multi-objective sequence optimization problems. Further, performance of the proposed algorithm can be tested on banchmark problems as well as compared with the other multi-objective optimization algorithms.

ACKNOWLEDGEMENT

The authors would like to thank Engr. Asif, for providing the Industrial data and University of Engineering & Technology, Taxila, Pakistan, for funding this research.

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