Mixed Model Assembly Line Sequencing In Make to Order System with Available to Promise Consideration

N. Manavizadeh , A. Dehghani , M. Rabbani

***Abstract*—**Mixed model assembly lines (MMAL) are a type of production line where a variety of product models similar in product characteristics are assembled. The effective design of these lines requires that schedule for assembling the different products is determined. In this paper we tried to fit the sequencing problem with the main characteristics of make to order (MTO) environment. The problem solved in this paper is a multiple objective sequencing problem in mixed model assembly lines sequencing using weighted Sum Method (WSM) using GAMS software for small problem and an effective GA for large scale problems because of the nature of NP-hardness of our problem and vast time consume to find the optimum solution in large problems. In this problem three practically important objectives are minimizing: total utility work, keeping a constant production rate variation, and minimizing earliness and tardiness cost which consider the priority of each customer and different due date which is a real situation in mixed model assembly lines and it is the first time we consider different attribute to prioritize the customers which help the company to reduce the cost of earliness and tardiness. This mechanism is a way to apply an advance available to promise (ATP) in mixed model assembly line sequencing which is the main contribution of this paper.

***Keywords*—**Available to promise, Earliness & Tardiness, GA, Mixed-Model assembly line Sequencing.

I. Introduction

TODAY the increasing competition in firms and high fluctuations and large variety in demand is an important subject that cannot be neglect. These pressures compel firms improve the performance of their production processes in order to supply the finished goods for customers within a short delivery time and with the lowest possible cost. One of the most relevant production environments that deal with these problem are Mixed-Model assembly lines. A mixed model assembly line is assembly line in which some product type that mostly have similar property with some insignificant difference are assembled. Mixed model assembly lines can be found in many firms to meet diversified demands of consumers without holding large amount of inventories unlike mass production assembly lines.The nature of the manufacturing environment and its place in supply chain determine the firms' strategy for produce their product in make-to-order (MTO) or make-to-stock (MTS). This strategies mainly elect: if a firm is at the upstream part of the supply chain network, MTS production is select and select MTO production at the downstream parts of supply chain network where is close to the end customers[1]. Many of the firm that has is close to the end customers. For example care production companies .for these firms it is better to follow a make-to-order (MTO) policy. This policy helps them to reduce the lead time when a random arrival sequence of different model types is received from customers. The other main characteristics that many mixed model assembly lines in MTO environment have are: small numbers of work stations, lack of mechanical transferring system, and highly skilled and versatile workers [2].

The design an optimal or near optimal sequence for mixed model assembly lines in a make-to-order environment with some different objective and constrain and consideration about human factors discussed in this paper. A number of performance metrics such as, tardiness and earliness, responsiveness, production rate variation have been considered. Because of the product variety in products, itself is not efficient and must be manipulate. The balancing and sequencing approach used for handling this problem. The balancing problem was first solved, and then the sequencing problem is considered. The purpose in balancing problem is to distribute the workload of a given mix model between stations evenly to meet some other objective like minimum line length, cycle time etc .the workload is balanced for the duration of the entire shift. Nevertheless, balancing the line singly is not efficient and often resulted in uneven workload along the line. In second stage we need to sequence the model release into the line. The objective in this stage is minimizing the blockage and starvation of any stations due to variation in station time that occur because of changes between the different models. Mixed model sequencing problem is done to optimize some variable such as raw material demand deviation, cycle time, idle time, line stoppage, work-in-process etc [3].There are so many characteristics that affect our problem. The nature of the

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products, line and station, the consideration about human factors, the predetermine constraint which impose to problem, and the goals that we want to attain them.At first we discuss about the most prominent objective that we want to satisfy it:Maximize responsiveness. The Available To Promise (ATP) is defined to satisfy this performance metrics. Two kind of ATP is exist, the conventional and the advanced which their functional scope can vary significantly. Conventional ATP, commonly implemented in ERP and determines the availability of finished goods at certain points of time in the future .But the advanced ATP provides wider scope, such as order quantity and due date quoting based on available supply chain resources and alternative measures in case of an anticipated shortage of finished goods and resources[4]. Advanced available-to-promise (AATP) comprises of a set of methods and tools to enhance order promising responsiveness and order fulfillment reliability. The most important goals pursued with the implementation of ATP are:

1. Be punctual by generating reliable quotes.
2. Reduce the number of missed opportunities by employing more effective methods for order promising
3. Improve the profitability and manage revenue by increasing the average sales price [5]

To achieve these goals, firms must support customer requests. They want to request their own product, in their specific quantity and in their predetermined delivery time window in other word they must support order quantity and order due date quoting. In order to achieve this goal we use a MADM technique to rank the customers and then by a penalty cost which set by each customer, apply AATP in our problem to find the best quoted time for each customer in each time a customer come in our company and request an order. Minimizing total earliness and tardiness costs help us achieve this goal. These days customers expect the firms to be more punctual so early delivery as well as late delivery is seen undesirable. Early jobs prevent circulation of capital and cause holding costs. In other hand and the effects of tardy jobs are dissatisfied customers and, if continue, the loss of reputation and goodwill will happen. So we must avoid these event and costs by considering them in our problem

II. Litrature Review

A. Review Stage

Mixed model assembly lines are a production line type where a variety of products models similar in some characteristics are assembled. Sequencing problems in this environment have received significant attention in recent years. This type of problem became important with highly increasing competition between production companies. most of these problem are proposed in mto environments because of the characteristic in such production systems. In this section we review some important and relevant article that attempt to solve the problem find in this area.At first in some references the balancing and sequencing of a have been solved. Merengo et al are one of them that developed heuristics for solving the balancing–sequencing problem sequentially [6]: (1) minimizing the rate of incomplete jobs or the probability of blocking/starvation events (2) reducing WIP. The balancing problem also minimize the number of stations; and the sequencing technique provides a constant parts usage, which is an important goal in JIT production systems however e assume that our line had been balanced and the number of stations are constant and fixed. Nils Boysen et al in their article introduced a comprehensive survey that classified all of the variable that may effect in mixed model assembly line [7]. They introduced three main planning approaches in mixed model: mixed-model sequencing, car sequencing and level scheduling and then in the concept of they introduce all basic elements. They categorized this functional element in 3 main type: á: Operational characteristics of the stations, â. Characteristics of the assembly line and ϒ. Objectives to be followed and used tuple-notation to show these. According to tupelo notation mentioned in this reference. Also in this article some of the other article has been categorized and their characteristic classified according to the tupel-notation.In order to consider the MTO constraint , we can use the Bukchins ‘work [2]. Because of the MTO environment condition, the intermixed demand is received that is randomly distributed according to demand proportions. The need to highly skilled workers in is shown and modeled in this article. This article mainly discuses the line balancing problem in. Ponnambalama et.al introduced a multi objective sequencing problem in their paper [8]. They mentioned that three practically important objectives are considerable in sequencing problem: 1. Minimizing total utility work, 2. Minimizing the variability in parts usage, and 3. Minimizing total setup cost. Then they use two mechanisms of genetic algorithm to perform some efficient solution. At the end of the article they mentioned that these objective functions are important to have an efficient sequence, especially when the configuration of stations in line is given and is not allowed to be modified. Rabbani et al. had developed a new approach for mixed-model assembly line sequencing with multi objectives [9]. In their paper, they consider three opposing objectives like: minimizing total utility work, total production rate variation, and total setup cost such as [8] paper. The assumptions In this paper were: 1) The line is partitioned into J given stations, 2) It is assumed that the stations have close boundary and the conveyor system moving at a constant specified speed, 3) The worker move down accompanied by the conveyor while performing tasks, 4) the worker moves upstream when they work on given product complete and 5) early start scheduling is determined such as many scheduling problems. All these assumptions are common with supposition that we consider in our problem. Because of opposing nature of objectives, they used a fuzzy goal programming to find efficient sequence in. They solved a comprehensive example and showed that this fuzzy approach can determine the optimal sequence of in their conditions.In other article in sequencing problem, authors solved a similar problem with three above mentioned objective by two other new approaches [10]: A hybrid multi-objective algorithm based on Particle Swarm Optimization (PSO) and Tabu Search (TS). Also Rahimi-Vahed et al. have solved a similar problem with the same objective by shuffled frog-leaping algorithm [11]. A memetic algorithm by Tavakkoli-Moghaddam, and Rahimi-Vahed also have been used in this problem [12].A Sequencing Problem for a Mixed-Model Assembly Line in a JIT Production System is discussed in an [13]. They said that in many JIT productions system the line stoppage time is more important than the production rate variation (PRV) and the objective function in this paper is minimization of total line stoppage time. However the PRV is one of the most important causes of line stoppage and we consider the PRV in our paper. At the end of the article they solved the developed single model problem with branch-and-bound method.A sequencing problem to level the part usage rates and workloads for a mixed-model assembly line with a bypass sub line strategy is studied in [14]. Work over load is defined as sum of differences between real completion time in the workstation and due dates, which depends on the time window value in each station. There are some different strategies which can be selected in the term of overload such as: stop the line, using utility workers or utilizing bypass sub line. In this article the utility work was applied. In another article [15], the second were chose such as our selection. The main goal considered in their paper is to leveling the part usage rates and workloads. To solve the developed model three different algorithms were applied: goal chasing method, tabu search and dynamic programming. In another recent paper [16] line stoppage cost has been considered and fuzzy programming approach used to find an optimal sequence in an. Reference [17] shows a simulated annealing (SA) algorithm is apply to solve the sequencing problem. The Simulated Annealing technique has been presented to production an efficient sequence in problem. Another objective that may we can consider in MTO environment is minimization of earliness and tardiness costs. As previously mentioned we choose the MTO production system in order to satisfy the customers in the variety, quantity and due date and if we can’t do this we will endure a heavy cost. One of the ways we can prevent these costs is to define an objective function that consider these cost. The cost of earliness and tardiness is appropriate one. Reference [18] is an article in this context. The authors define 3 objectives: minimize the weighted sum of E/T penalties, and to maximize the smoothness of the production flow of the .they investigated their model in apparel industries. In order to have a main reference in E/T penalties concern with single and parallel machines and the different model we can use the survey article done by Gordon et al. [19]. In their article a detailed classification of linear and quadratic penalty has done. In addition to the exact models in E/T, they mentioned that “In many case, due dates are negotiated rather than simply dictated by the customers The later the due dates are fixed, the higher the probability that the product will be completed or delivered on time”. In this subject we can use some other researches [20], [21], [22].One of the main characteristics in production lines is the shape and layout of the line. In this paper an important topic is the shape of our assembly line. For assuming this characteristic in our problem we must know about the properties and precondition of a given line shape in which later can apply them in our problem. In some reference it shown that one of the best applicable types of line is U-shape line and they illustrate that the benefits are impressive. The main characteristics in a u-shape line are:

- The U-line arranges machines around a U-shaped line in an operators work inside the U-line.
- U-lines are rebalanced periodically when production requirements change
- The operators must be multi-skilled and versatile to do several different processes.
- It requires operators to walking.
- When setup times are negligible, U-lines are operated as mixed-model lines where each station is able to produce any product in any cycle
- When setup times are larger, multiple U-lines are formed and dedicated to different products.

Miltenburg has a comprehensive article in the subject of U-shape production line [23]. In his article the benefits of U-shape line was mentioned and by some statistic information they are proved for all. We can have these benefits by applying this U-shape line in the condition of our problem definition. At the end of this part it is remarkable that any other condition that we need to consider will be present in the future in model and notation.

III. Problem Definition

In this paper, our line is a u-shaped conveyor system moving at a constant speed (v). All of the products are launched onto the conveyor at a fixed time interval. The line is partitioned into k stations. It is assumed that the stations are all closed types. A closed station has boundaries, which workers cannot cross. Such a closed station is often found in reality in which the use of facilities is restricted within a certain boundary. The tasks allocated to each station are properly balanced and their operating times are deterministic. The worker moves downstream on the conveyor while performing his/her tasks to assemble a product. To complete the job, the worker moves upstream to the next product. The worker’s moving time is ignored. If an operator can’t do his/her work in station boundary, a utility worker will help him/her.The design of an assembly line involves several issues such as determining operator schedules, product mix and launch intervals. Two types of operator schedules early start schedule and late start schedule, are found in [3]. An early start schedule is more common in practice and is used in this paper.The nature of the production system in this article is make-to-order. This kind of production system have some characteristics such as Random arrival sequence of different model from different customers, Small number of work station, lack of mechanical conveyor, highly skilled operator and etc. Then the assumption in this paper is:

1. Variety of products model and customers priority is considerable.
2. Workers are Versatile, and then they can do different tasks in their station. In product system without versatile worker each task must be done by a determined operator. Then the sequence can't be well optimized. Moreover our line is u-shaped and if we want to benefit from this line shape, we must have versatile and agile worker which can operate on two legs of the product line.
3. Dynamic demand is assumed in this paper. May be the planned demand is changed in the beginning of the time horizon. Also some real time demands in different time are interred from different customer. We must answer to this customer (in short time). And quote a precise due date to the customers. To meet this, we run MADM model to find the customer priority and then run sequencing model to find the best due date for each customer. Because of some restriction of considering MPS vector in priority of customers, we neglect it and assume that all of orders are considered completely. This is a way to order promising in our model, and a way to involve AATP in the mixed model assembly line.
4. Machine break-downs as well as staff absenteeism are not considered in this model. Also there is no materials shortage. Also set up time are spited and considered in each processing time.
5. In a case of over load in a station, we use utility workers. a utility worker is an operator who gathered over load in stations and help operator who in his/her station overload occurred. Work overload is measured by the time a necessary to complete all work in excess of the respective station's time border. A work overload has no impact on the succeeding station. Thus, the model assumes that the work overload is either compensated by utility work.
6. A U-shaped line layout with crossover stations is used in [24] In principle, the physical layout of the line is not relevant for the sequencing decision .However; a U- line allows operators to work on more than one work piece per cycle at deferent positions on the line, because crossover stations have access to two legs of the U-shaped line simultaneously. This influences the sequencing problem considerably [7].
7. The priority of each customer calculate by some MADM methods like AHP by given different criteria such as due date, profitability, loyalty , flexibility, and etc [25]. after this, different penalty was used in early/tardy costs to show this ranking and priorities. In this paper we assume that previously the priorities of customer were determined. It means that base on some different criteria we ranked the customers. Each time a new customer inter the firm, this ranking revised. To show the priority of each customer, we use some different amount of penalties. To meet AATP goals and satisfy customers in best way we use partial delivery strategies. This strategy has some additional cost [4].We will assume that the demand of each customer which can partially delivered and it cost is predetermined.

In this paper we assume three objectives function FIRST, minimizing utility work. SECOND minimizing product rate variation and THIRD maximize the responsiveness by minimizing total early/tardy cost.

Notation:

c: set of customers
m: set of models
k: set of stations k=1,..,K
i: number of product in sequence $i=1,\ldots,I$, $I=\sum_{c=1}^{C}\sum_{m=1}^{M} d_{mc}$
*v:*Speed of conveyor (constant)
l_k :Length of station k
C: Cycle time
r_m : Target production rate of model m
p_{mk} : Processing time of model m in station k
dd_{mc} :Quoted due date by customer c for model m
c^e_{mc} :Earliness cost for customer c and model m
c^t_{mc} :Tardiness cost for customer c and model m
y_{mic} : y_{mic}: Total cumulative production quantity of model m up to cycle i for customer c
x_{mic} : $\begin{cases} 1 & \text{If a copy of model m for customer c produce in sequence place i} \\ 0 & \text{Otherwise} \end{cases}$
c_i :Completion time for i th product in sequence.
$z_{i,k}$:The starting position of the work on the i^{th} product in a sequence at station k
$U_{i,k}$:Utility work needed for station k in sequence i

IV. Proposed Model

A. Minimize total utility

The utility work is typically handled by the use of utility workers assisting the regular workers during the work overload. Let l_k be the fixed line length of station j and U_{ik} be the amount of the utility work required for product i in a sequence at station j. this work is done by Hyne et al [26]:

$$MinA = \sum_{k=1}^{K}\left(\sum_{i=1}^{I} U_{ik} + z_{(i+1),k} / v\right) \quad (1)$$

$$\sum_{m=1}^{M}\sum_{c=1}^{C} d_{mc} = I \quad (1.1)$$

This equation ensures that the places in sequence equal to total demand.

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{c=1}^{C} x_{imc} = 1 \quad (1.2)$$

ensures that exactly one product is assigned to each position in a sequence.

$$\sum_{i=1}^{I} x_{mic} = d_{mc} \qquad \forall c, m \quad (1.3)$$

Eq. (1.3) guarantees that demand for each model for each customer type is satisfied.

$$z_{(i+1)k} = \max\left[0, \min\left(z_{ik} + v(\sum_{c=1}^{C}\sum_{m=1}^{M} p_{mk} \times x_{mic}) - c \times v, l_k - c \times v\right)\right]$$
$$\forall i, k \quad (1.4)$$

This equation indicates the starting position of the worker at each station *k* on product i+*1* in a sequence.

$$U_{ik} = \max\left[0, \left(z_{i,k} + v\sum_{c=1}^{C}\sum_{m=1}^{M} p_{mk} \times x_{mic}) - l_k\right)/ v\right] \quad \forall i,k \quad (1.5)$$

Utility work ($U_{i,k}$) for the i th product in a sequence at station *k* is determined by above equation

$$z_{1k} = 0 \quad \forall k \quad (1.6) \; \& \; (1.7)$$
$$z_{i,k}\,, \quad U_{i,k} \geq 0 \quad \forall i, k$$

$$x_{mic} = \begin{cases} 1 & \textit{If a copy of model m for customer c produce in sequence place i} \\ 0 & \textit{Otherwise} \end{cases} \quad (1.8)$$

B. Minimize production rate variation

One basic requirement of JIT systems is continual and stable part supply. Since this can be realized when the demand rate of parts is constant over time, the objective is important to a successful operation of the system. Thus, objective can be achieved by matching demand with actual production. The following model is suggested by Miltenberg [27].

$$Min \sum_{i=1}^{I}\sum_{m=1}^{M}\left|\sum_{i=1}^{i}\left(\frac{\sum_{c=1}^{C} x_{mIc}}{i} - \frac{\sum_{c=1}^{C} d_{mc}}{I}\right)\right| \quad (2)$$

Constraints: (1.1), (1.2), (1.3), (1,8)

The first term in the objective function is the production ratio of model m for all customers until product *i* is produced and the second term is the total demand ratio of model *m*.

C. Minimize earliness and tardiness cost

$$\min \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{c=1}^{C} C^{e}_{m,c} \times E_{m,c,i} + C^{t}_{m,c} \times T_{m,c,i} \quad (3)$$

The objective function minimize total earliness and tardiness cost of each customer

$$T_{m,c,i} = \max\left\{0, \left(c_{m,c,i} - dd_{mc}\right)\right\} \quad \forall m, c, i \quad (3.1)$$

$$E_{m,c,i} = \max\left\{0, \left(dd_{m,c} - c_{m,c,i}\right)\right\} \quad \forall m, c, i \quad (3.2)$$

These two constraints calculate the early time, tardy time for each customer and models.

$$C_{m,c,i} = i \times c + \max\left\{\sum_{k=1}^{K} p_{m,k} \times x_{m,c,i}, v \times \sum_{k=1}^{K} l_k\right\} \quad (3.3)$$

And constraint (1.1) , (1.2), (1.3), (1.8)

The first term in this constraint calculate the initial time when a customer demand of model m inter the , and second term calculate processing time of each product, based on processing time in each station and speed of conveyor and total line length. For completion time we assume that because we use utility work, over load and idle time don't occur. We relate the costs to the customers and models indices to show the effect of customers' priorities. For calculating these, we use [28] and developed it based on our assumptions. This is our contribution in this paper. Each customer have first priority, cant changed in latter sequence scheduling. It mean this customer demand become fixed in planning horizon and can't be changed.The AATP model runs for each order received from multiple customers that arrived in random and undetermined times. Each customer provides only one requested delivery date for each product type. The supply chain can provide a customer with ordered products by splitting orders over multiple time periods before and after the requested delivery date of the customer. The supply chain attempts to deliver ordered products to the customer fully and exactly on the requested delivery date of the customer. Some of The orders already received May subject to further changes in a current supply chain plan. Any newly arrived orders are not allowed to alter the committed delivery dates of those already received but may cause postponement and preemption is accepted. For ranking the customers we use AHP method and determine three main attribute: profitability, due date and customer long term effect on our firm. This matrix shows each customer weight and score in each attribute:

$$\begin{array}{c} \text{Attribute a} \\ \text{Customer c} \begin{bmatrix} w_{11} & \cdots & w_{1a} \\ \vdots & \ddots & \vdots \\ w_{c1} & \cdots & w_{ca} \end{bmatrix} \end{array}$$

If the rank of customer c become R, in model c, then the earliness and tardiness cost become a function of $R_{c,m}$ so that show the importance severity of each customer type in best way. For quoting a due date we can assume the customer due date and contract amount of tardiness job of each customer as partial deliver in the end of production time for the customer demand and by this, reduce tardiness costs. These equations calculate the early and tardy cost for each model and customer.

$$c^{t}_{c,m} = round\ (2^{10-R_{c,m}})$$
$$c^{e}_{c,m} = R_{c,m}$$

V. SOLUTION METHODOLOGY

It is well known that majority of the industrial engineering optimization problems are non-convex and hard to solve by conventional optimization techniques. Recently genetic algorithms have received considerable attention as an optimization technique for solving the industrial engineering problems. GAs are inspired by Darwin's evolutionary theory. Since finding the best sequence for a mixed model assembly U-lines are so complex and NP-hard, and due to discreteness

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nature of this problem, GA is applied to solve the problem. The basic elements of a GA that must be specified for any given implementation are representation, population, evaluation, selection; operators and parameters must be designed for each problem separately. In this paper after using an AHP software and rank each customer order, we use a weighted sum method to find some efficient solution for sequencing problem at first by using mixed integer non linear programming by GAMS software for small problem, then we use a proposed WSM GA for the large problems. We use an integer GA because of the ease of application and crossover and to fit the GA with the nature of and the multi objectiveness. Applying this integer GA increases the flexibility of the chromosomes and eases the crossover and mutation operations.

Genetic Algorithm (GA) pseudo code:

HStep 1: Initial population:

Generate initial population randomly.

Step 2: Genetic operators:

Selection: elitist strategy in enlarged sampling space/ or RW /or tournament /or ranking

Crossover: crossover operator

Mutation: mutation operator

Step 3: Evaluation:

Do fitness test using the offspring satisfying constraints.

Step 4: Stop condition:

If a pre-defined maximum generation number is reached or an optimal solution is located during Genetic search process, then stop; otherwise, go to Step 2.

Chromosomes:

A chromosome is a set of parameters which define a proposed solution to the problem that GA is trying to solve. In our problem, a chromosome length is equal to number of sequence place and the value of each gene the number of product which previously assigned. Each number in the permutation of the chromosome have a comprehensive structure which define the penalty cost, processing time and the other parameters that assigned to each product model and customer.

Fitness function:

A fitness function is a particular type of objective function that quantifies the optimality of a solution in a genetic algorithm .GAs manipulates solutions at the string or chromosome level based on fitness values to propagate similarities among the high performance strings to the next population using reproduction operators such as mutation and crossover. In the proposed genetic algorithm the fitness function value of each solution is sum of equation(1) and (2) and (3), which before scaled between 0 and 1, by divided with the maximum values for these objective according to previous runs.

Selection:

The sampling mechanism chose for selecting solutions (chromosomes) from sampling space is Roulette Wheel selection method which is a stochastic sampling approach. In this method, for each chromosome, a selection probability proportional to its fitness function value is determined and solutions are selected using the calculated probabilities for performing crossover and mutation operations. Assume that the fitness function value for solution j is Fitness (solution (j)), the selection probability of the chromosome will be calculated from the following equation:

$$prob(Solution(j)) = fitness(Solution(j)) / \sum_{j=1}^{npop} fitness(solution(j))$$

Crossover:

In this problem we use a permutation to produce a chromosome and to do crossover, as shown in Fig. 1, one crossover point is selected, the permutation is copied from the first parent till the crossover point, and then the other parent is scanned and if the number is not yet in the offspring, it is added.

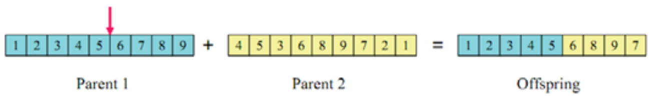

Fig. 1 single point crossover for permutation encoded individuals

Mutation:

Two numbers in the string are selected and exchanged as shown in Fig. 2

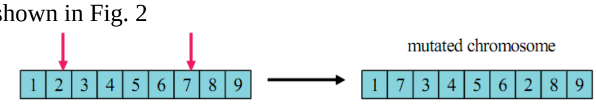

Fig. 2 Single-point crossover for permutation encoded

VI. Experimental Result

The proposed model is coded by GAMS software for small size problem first, and then a proposed GA coded by MATLAB for large size problem. Data and some different test problems solved using GAMS and GA for these problems presented in tables. It is obvious that GAMS can't handle a big size problem and GA in a best way solves the proposed problem.

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TABLE I
ASSEMBLY TIMES AND WORK STATION LENGTHS

Workstation	model			workstation length
	1	2	3	
1	4	8	7	12
2	6	9	4	14
3	8	6	6	12
4	4	7	5	11

TABLE II
QUOTED DUE DATE

quotated due date			
model	costumers		
	1	2	3
1	200	200	390
2	100	400	300
3	150	400	300
4	1000	110	200

TABLE III
EARLINESS COSTS

earliness cost			
model	costumers		
	1	2	3
1	1	0	1
2	2	1	1
3	2	2	1
4	5	2	1

TABLE IV
TARDINESS COSTS

tardiness cost			
model	customers		
	1	2	3
1	5000	20	50
2	2000	10	30
3	1000	20	50
4	1000	30	60

TABLE V
EXAMPLE PROBLEMS

	GAMS			GA			
	optimum obj. function value	best sequence	Execution time	optimum obj. function value	best sequence	execution time	Gap
problem1(4,4,4)	51.212	(1,2,2,1,3,1,1,2,3,3,3,2)	0.016	130.45	(2,1,3,3,1,3,3,2,2,2,1,1)	30.11	79.238
problem2(4,4,2)	36.952	(1,3,1,3,2,2,2,1,1,2)	0.015	119.39	(2,1,3,3,1,2,2,2,1,1)	27.713	82.438
problem3(4,3,3)	37.452	(1,3,3,3,1,2,2,1,1,1)	0.015	128.86	(2,1,3,1,3,3,2,2,1,1)	22.75	91.408
problem4(4,6,2)	50.212	(1,2,1,1,2,2,1,2,3,2,3,2)	0.032	143.65	(2,1,2,2,3,1,2,3,1,1,2,2)	28.12	93.438
problem5(6,3,3)	51.712	(1,3,1,1,3,2,1,2,2,1,3,1)	0.016	136.23	(1,1,1,2,3,1,2,3,1,3,2,1)	29.12	84.518

TABLE VI
EXAMPLE OF LARGE PROBLEMS

Work station	Model 1	2	3	4	5	6	7	8	9	10	Station length
1	6	4	10	3	3	5	0	10	9	4	10
2	7	1	4	0	5	7	6	6	9	7	11
3	3	2	0	2	10	3	3	8	4	10	10
4	6	2	3	7	7	1	10	6	6	8	10
5	8	3	8	7	9	5	10	0	9	5	12
6	0	1	8	9	4	3	3	4	10	8	14
7	0	3	5	6	5	8	8	7	7	4	8
8	10	1	7	0	6	8	9	5	2	10	10
9	7	9	9	10	2	7	6	4	7	10	10
10	2	1	0	8	8	1	9	10	0	9	12

GAMS can’t solve large size problem because of the N-P hard nature of the sequencing. Because of this, we use only GA in large size. In the large size problem we consider 10 stations and 10 models, 5 different problems have been solved in.

TABLE VII
EXAMPLE OF LARGE PROBLEM

Large problem	best sequence	objective function	execution time
problem1(2,2,2,2,2,2,2,2,2,2)	(8,8,4,6,1,4,9,3,7,3,9,1,2,2,6,5,7,5,10,10)	125.98	25.43
problem2(2,2,3,1,2,2,2,2,3,1)	(5,2,3,3,7,1,4,9,6,1,2,10,9,3,5,6,7,8,8,9)	144.32	24.93
problem3(5,5,0,5,0,5,0,0,0,0))	(4,4,6,1,2,2,4,2,6,6,1,1,2,4,1,2,1,4,6,6)	148.23	23.98
problem4(8,7,5,0,0,0,0,0,0,0)	(1,2,3,2,2,1,3,1,2,1,2,1,1,2,1,2,1,3,3,3)	155.21	22.34
problem5(4,4,4,4,4,0,0,0,0,0)	(3,1,5,4,5,2,4,2,3,5,5,3,2,1,1,2,1,3,4,4)	137.76	24.65

VII. CONCLUSION

A comprehensive modeling for multi-objective mixed model assembly line sequencing was proposed whereas model the assembly line environment as real as possible, to achieving MTO approach and reducing some different objective function. Therefore the production rate variation, utility work and earliness, and tardiness costs are defined as objectives. This consideration specially are crucial in mixed-model assembly U-lines (for example assemble of automobile and trucks and etc).this big mixed integer problem is first solved by GAMS and then for large scale problems we used a proposed GA. Some data sets were used to test the performance of the proposed GA. The computational results showed that the GA performs well and were able to solve large-scale problems in an appropriate time. Flexibility of the proposed model allows managers to deal with different situations in the real assembly lines environment because of the considering the priority of customers and different penalty cost based on the priorities. This is a good way to set the ATP for make to order environments. For the future research, it is good to consider higher level for acceptance rejection of customer's demands and then consider different penalty costs; also it is good to consider capacity reservation to have a proper policy for ATP in MTO systems.

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