Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2015/03/jls.htm
2015 Vol. 5 (S3), pp. 1874-1885/Rezayee and Darestani
Research Article

PROPOSITION OF A MAINTENANCE, REPAIR AND OVERHAUL SUSTAINABLE POLICY OPTIMIZATION MATHEMATICAL MODEL AIMED AT ENHANCING THE USER SATISFACTION, CURTAILING COSTS AND PREVENTING PRODUCTION DOWNTIME

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ABSTRACT
Given the importance of integrated manufacturing planning in manufacturing systems on the one hand and the importance of maintenance, repair and overhaul for manufacturing systems on the other hand, several separate models have been proposed in recent years for integrated manufacturing planning and scheduling of maintenance, repair and overhaul. This paper explores the problem of integrity in manufacturing, maintenance, repair and overhaul as two main categories in the field of manufacturing and service-delivery. For this purpose, a review of literature and identification of research gaps, required assumptions and explanation of the problem were conducted to ultimately present a mixed integer nonlinear mathematical model. Then, appropriate data were collected based on a case study in Mashhad Urban Railway to be included in the model. The performance of the algorithms was ensured through examining the results of implementation. There are 3 examples offered for each different size. The application of imperialist competition algorithm was facilitated through comparing the model and Lingo solution based on one size.

Keywords: *Mathematical Modeling, Integration of Manufacturing and MRO, Imperialist Competition, Case Study*

INTRODUCTION

Maintenance, Repair and Overhaul (MRO) planning is one of the most important issues related to manufacturing and even service organizations. Although the need for MRO units at organizations is deeply felt, most Iranian organizations can be regarded as proponents of the post-failure planning approach unlike many other organizational units employing accurate and scientific methods, models and techniques for calculations.

In this context, several variables can be considered in designing such an important policy, among which the application of content analysis in the literature review can provide a relatively comprehensive view of the most important variables used to identify the conceptual model (Sie *et al.*, 2011).

Accordingly, the main objective of this research can be internally dependent simultaneous optimization regarding three distinguished objectives where the stabilization of decision in this area should also be considered. The final output of this research is appropriate policy-making for attaining the goals with the least volatility during the planning period. In line with this goal in mind, the researchers thought about "how and under what circumstances a Preventive MRO planning should systematically lead to overall efficiency through other measures taken?

The research discusses another alternative approach to the task of maintenance, repair and overhaul and how to carry out it in a way to increase profitability. This notion can be different from other philosophies and ideas concerning MRO, even though it can be raised as a mindset or values for the new millennium vision.

Many qualitative studies have so far been conducted in the area of policy design and maintenance, which seek to evaluate and improve the effectiveness of different forms of MRO in their corporate decisions. However, this paper intends to adopt an integrated approach, unlike the previous works, so as to examine the interactions between financial, manufacturing, marketing objectives, etc. Hence, this integrated approach can be regarded as the innovation in this study in terms of quantity using mathematical modeling.

Relevant Literature Review

The predictive models and decision-making on high-performance equipment as well as correct response to customer needs are essential for manufacturers. Rapid response refers to fulfillment of customer demands for goods and services from the manufacturing stage to the delivery of goods or services.

This cycle often involves the raw materials and components supplier to the manufacturing and distribution agent and ultimately the client (Perry and Sohile, 1999).

In view of the competitive market that demands quick response, the product or service controller must be aware of a variety of factors focusing on issues such as allocation of tasks, repairing machinery and providing supplies through adopting appropriate decisions.

The objective in this case is to reduce manufacturing costs, improve product quality and delivery time to the customer. Poor decisions can lead to an increase in the costs and failure of service-delivery (Cooling and Johnson, 2002).

Today, mass manufacturing has undergone attitude shift toward special mass manufacturing. Therefore, mass manufacturing should be replaced by batch manufacturing under flexibility of manufacturing systems (Irani *et al.,* 2004).

Modern technology and new equipment can help support this goal, but there are more complex issues in MRO directed to the service provider (Hipkin and Cook, 2004).

The Just-In-Time notion is exclusive to rapid response to customers (White *et al.,* 1999).

Professionals often mention JIT as a philosophy that can assemble in real time and numbers required (Benton and Shin, 1994).

Hence, the most important feature of the JIT can be summarized in the following 4 elements (Bicock and Orwell, 1998)

1. Desired product
2. Required quantity
3. Delivery to the desired station
4. At the moment of need

The following assumptions can be proposed as the foundations of the JIT system (Yu *et al.,* 2003):

1. The Kanbans must constantly move between stations.
2. Shipping time will be ignored between stations.
3. Demand is steady and processing times will follow a normal distribution.
4. Machine downtime can be repaired quickly.

In fact, these assumptions can be assessed as unrealistic. Especially in the case of machine failure assumption that can occur suddenly without being repaired quickly. Although information technology could greatly reduce these controls, these items can lead to an imbalance in manufacturing system and manufacturing control programs.

There are several immediate control methods for rapid response capacity. Hernandez *et al.,* (2006) employed the moment manufacturing control factor for careful planning.

To provide an accurate estimate and judgment on the basis of manufacturing, Cooling and Johnson proposed the automatic data collection for effective planning (Cooling and Johnson, 2002).

Qian *et al.,* proposed a maintenance knowledge model in the form of an expert system for fault detection caused by chemical processes (Lee *et al.,* 2005).

The proposed model will allow the knowledge-based engineers to improve their knowledge based on fuzzy language and the complexities.

Karasuka also adopted a multifunctional system for solving the robot control problem (Yao and Carlson, 2004).

This method allows different processes to be integrated with each other at crucial moments. Similarly, Du *et al.,* benefited from information technology and sensors to control manufacturing system (Baggio *et al.,* 2006).

They believed that the decision-maker can easily take an appropriate decision by collecting these data through an information system.
MRO can dramatically reduce manufacturing costs, improve performance and the ability to stabilize manufacturing (Du *et al.*, 2007).
A great deal of research nowadays has been focused on the importance of MRO maintenance and its strategy (Hipkin and Cook, 2002).
MRO is the first method of policy, including urgent-based maintenance, condition-based maintenance, downtime-driven maintenance, Internet-centric design and Internet-based detection.
Selection of a suitable maintenance policy can be a key decision in the new manufacturing systems. However, most of the manufacturing controls focus on breakdown and quick fix (Fal and Wang, 1996).
The failure of a machine must be followed be quickly allocating the machine task to another or task need to wait until the current machine is repaired. The distinguishing point can be regarded the balance between maintenance costs and repair/replacement.
If the waiting cost is less than the cost of replacement in repair mode, then the correct decision is to wait, otherwise replacement should be conducted. However, this problem requires information that could be of great uncertainty (Al-Najjar and Alyusef, 2003).
One of the causes of uncertainty in planning environments is adequate previous information (Pitleson, 2004).
The advent of computer information systems can provide documentation and machinery. In many process systems, information are produced and stored in real-time.
It seems difficult to use numerical methods in situations where many manufacturing laws entail complex structural variables and multiple rules (Wong, 2002).
The sources of uncertainty generally include the poor explanation, lack of transparency, irrelevant and confusing data (Al-Najjar and Alyusef, 2003). Moreover, an appropriate indicator cannot simply be proposed to assess the decision.
Usually, contingency fuzzy variables and intervals are applied to display the uncertainty data in decision-making. The Bayesian theory also considered important methods to manage uncertainty in human decision-making (Cooling and Johnson, 2002).
The theory of fuzzy sets is also an important measure for uncertainty in the field of manufacturing control. Al-Najjar and Alyusef employed a multi-criteria model for the MRO decisions (Scarf, 1997).
Sokolovski used the rules for monitoring and control in garment manufacturing (Sabram and Haghani, 2003).
Zhang and Tem employed a fuzzy simulation model to analyze the uncertainty of needs and resources (Negneviski, 2003).
The application of neural network and fuzzy logic aims to estimate reliability and equipment failure as an important role in evaluating the performance of any system. Reliable forecasts are important from many aspects, most notably the manufacturing planning, MRO planning and evaluation of reliability, breakdown detection and risk assessment (Maccola, 1999).
Machine reliability modeling is a key issue in mining and other industries. Having knowledge of reliability before acting can enable individuals to predict appropriate preventive and corrective MRO. Most models of system reliability are based on distribution models for lifecycle, failure analysis tree and Markov models. Each of these approaches has advantages and limitations. The traditional models of reliability cannot respond to dynamic operating conditions (Zadeh, 1993).
Furthermore, many system reliability models available operate based on some basic assumptions. Such assumptions may not be true in the real world; therefore, preventive action is substantially different between the various models. Factors such as complexity, development environment and system development methodologies are effective in the design of complex models, facilitating nonlinear models and design. Under these conditions, the traditional reliability models entailing the assumption of independence and non-linear relationship between the variables are unsuccessful in obtaining satisfactory results.

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Reliability will change over time. Some researchers have regarded these changes as time series processes. The self-regressive average model is one of the ways to forecast time series (Box and Jenkins, 1976).
Hu and Sierra proposed such a model to analyze the failure of systems under repair. The two researchers managed to employ the model in combination with other models in predicting failures.
Recently, artificial neural network has shifted tremendous focus on time series prediction. This method is nowadays preferred as a data-based method over the more traditional ones (Hu and Sierra, 1998).
A unique feature of the neural network can be flexibility in practice and exploration of the complex nonlinear relationships between the input and output patterns through repetitive learning. However, the use of artificial neural network is limited to reliability predictions.
Liu *et al.,* used neural network models to estimate parameters of reliability distribution, concluding that the use of this method can provide results much clearer than traditional methods (Lulas and Olatonboson, 2008).
Ehsan and Amjadi proposed an expert system based on neural network to evaluate the reliability of the power network (Hui, 2007).
Using their moving average regression neural model, Su *et al.*, analyzed the reliability of engines, finding out that such models have better performance than traditional models like the moving average regression neural model (Ehsan and Amjadi, 1999).
Koh *et al.,* adopted a conceptual model in combination with a multilayer forward neural network and radial basis function in combination with neural network so as to estimate the reliability of engines. Practical results proved the fact that the proposed model performs better than the moving average regression neural model (Su *et al.*, 1997).
Cheng *et al.,* provided a neuro-fuzzy hybrid system for predicting the reliability of the engine system and compare the results, finding out that the proposed model for yielded far better performance than moving average regression neural model.
Perhaps the most important limitation in each data-based model (including neural network models) involves the proper fit of the data distribution at the beginning of the implementation of the trials (Su *et al.*, 2003).
There are two types of fitting problems in the literature on neural networks: Fitness higher or lower than reality. Such problems often occur due to poor choice of neural learning parameters, which include the learning rate, torque, size of covert nodes and hidden layers. The low fatnesses mostly lead to poor network performance data, while the fatnesses higher than reality lead to lower model generality. This occurs when the model is accustomed to the learning data (addiction) incapable of performing efficiently in face of new previously unseen data.
Therefore, the main challenge of neural network in avoiding the two unpleasant events above is the choice of appropriate learning parameters. The most common method in choosing such variables is a trial and error operating in cooperation with appropriate training data but yielding suboptimal results interacting with unseen data.

The Need for Research

Fierce competition together with advanced growing technology has brought many changes in the industry landscape. Products, methods, processes and new systems are steadily developed and put into operation. For that reason, it is essential to improve the operation of equipment through appropriate programs. Despite the rising cost of materials and personnel, there is a sustained effort to maintain or reduce operating and manufacturing costs. Thus, increasing effectiveness, efficiency, productivity, reliability, utilizing and exploitation of tools, machinery and equipment are an economic necessity (Rabatel *et al.*, 2011).
Since the volume of investments in the construction of industrial and manufacturing facilities is significant, appropriate management systems of MRO is crucial for preservation of the nation's capital. Moreover, an MRO coherent and sustainable organization is vital to optimize and increase the useful life of the devices, equipment, machinery and manufacturing facilities. Thus, appropriate MRO policies can play an important role in availability and reliability, quality and safety system (Ferrero *et al.*, 2012).

In general, preventive maintenance procedures include the information and data that define the periods of time into the service and inspection equipment in a way that MRO and operation units can effectively determine the downtime for maintenance and repairs or overhaul the equipment prior to malfunction, measures to increase the network reliability. Proper maintenance of equipment can significantly reduce total cost of operations and increase the efficiency of the plant.
However, ROS in the eyes of many administrative staff seems costly, whereas an optimistic and positive view points to greater profitability. The key to this approach lies in a new perspective through proactive MRO. By reviewing the common similar MRO techniques, the preventive, predictive and proactive styles can be derived.
In most organizations, the MRO is implemented through a cautious approach relying on conventional methods of maintenance, where new methods avoided so as to prevent complex problems and potential problems. Thus, a new approach to the MRO task involves not only maintenance, but also development of a process for the plant operating system. Prior to restructuring or any attempt to return the equipment back to initial operation, a redesign can be aimed at the development of processes.
The research discusses another alternative approach to the task of maintenance, repair and overhaul and how to carry out it in a way to increase profitability. This notion can be different from other philosophies and ideas concerning MRO, even though it can be raised as a mindset or values for the new millennium vision.
With the implementation of third generation maintenance and repair (MRO) in many organizations, the failures are curtailed by up to 100% and the MRO objectives can to a large extent be achieved. However, none of the MRO systems can guarantee complete removal of any failure (there is still minimal risk of unplanned downtime).
Therefore, a realistic process can lead to complete elimination or at least reduction of the frequency of defects. The fourth generation MRO developed due to rapid changes in the evolution of equipment and processes, mainly the use of fast, strong and advanced computers.
In the fourth generation, time can be the most important issue. According to the description given above, the third generation is shifting focus unto other MRO issues. In fact, the probability of failure is unacceptable in the design process of manufacturing lines, which is reduced almost to zero. Hence, the most important principles of fourth generation of MRO can be expectedly described as follow.
When examining the risk at high organizational levels, the behavior, strategic planning and maintenance are treated with special attention. The relationship between demand, product design and factory maintenance can be much more than the current situation. The rapid development in information technology serves to detect, predict and prevent possible damage.
Many qualitative studies have so far been conducted in the area of policy design and maintenance, which seek to evaluate and improve the effectiveness of different forms of MRO in their corporate decisions. This paper intends to adopt an integrated approach, unlike the previous works, so as to examine the interactions between financial, manufacturing, marketing objectives, etc. Hence, this integrated approach can be regarded as the innovation in this study in terms of quantity using mathematical modeling.
Knowing the type of modeling, accurate or meta-heuristic methods suitable in this area can be helpful to evaluate the performance considered as another innovation. Furthermore, the use of reliable information can help an industrial complex for performance evaluation model and its application in practice with real situations.

MATERIALS AND METHODS

Customer Satisfaction and its Measurement Methods

For an organization to be able to perform measurements of customer satisfaction, there should be a projection model and technique in this regard, so that a strong theoretical foundation determine the indicators for the purpose of assessment.
The different models and patterns of quality management by administration science researchers and economists and marketing experts for measuring customer satisfaction can be divided into two categories.

- Objective methods

These are measured through indicators that have a strong correlation with customer satisfaction, indirectly measuring the satisfaction of their customers. Due to their doubts on the validity, these methods are used less frequently.

- Conceptual theoretical methods

In this way, customer feedback is used directly to measure customer satisfaction. Therefore, these methods are more reliable than objective ones.

Mathematical Allocation Model and Flexible System Processing Tools

Based on the assumed characteristics, collections and indexes can be defined as follows:

Definition	**Symbol**
Determiner of task type	I
Determiner of machinery	K

Moreover, the list of model parameters is as follow:

Definition	**Symbol**
Time required for repairing machine k	$t_{r,k}$
Time required for repairing and preventive MRO on machine k	$t_{p,k}$
First Wibol distribution parameter	θ
Second Wibol distribution parameter	β
Processing time i on machine k	$pr_{i,k}$
Time for delivering task i	DD_i

Moreover, the list of model variables is as follow:

Definition	**Symbol**
If task i is defined after task j on machine k	$X_{i,j,k}$
If MRO occur right before task i on machine k	$y_{i,k}$
Time interval between two tasks on the machine right before task i on machine k	$buffer_{i,k}$
Time scheduled for task initiation on machine i under specified scenario w on machine k	$SP_{i,k}$
Real time scheduled for task initiation on machine i under specified scenario w on machine k	$SA_{i,w,k}$
Real time scheduled for task termination on machine i under specified scenario w on machine k	$FA_{i,w,k}$

Final model is as follows:

$$min\ Z = P_1 E\left[\sum_i \sum_k (SA_{i,w,k} - SP_{i,w,k})\right] + P_2 E\left[\sum_k T^r_{max,w,k}\right] \quad (0)$$

$$Max\ Z = \sum_i \sum_k \sum_w (FA_{i,w,k} x_{i,j,k} - SA_{i,w,k} x_{i,j,k})$$

S.t:

$\forall i,k$	$SA_{i,w,k} = SA_{i-1,w,k} + Pr_{i-1,k} + buffer_{i,k} + t_p y_{i,k}$	(1)
	$SP_{i,w,k} = Max\{SA_{i,k}\ ,FA_{i-1,w,k+t_p y_i,k}\}$	(2)
	$FA_{i,w,k} = SA_{i,w,k} + Pr_{i,k} + t_r \gamma_{i,k}$	(3)
$\forall i,w,k$	$T^r_{max,w,k} = max_i \max\{FA_{i,w,k} - DD_i, 0\}$	(4)
$\forall i$	$a_i = b_i + pr_{i,k}$	(5)
	$b_i = a_{i-1}(1 - y_{i,k})$	(6)
	$pr_{i,k} = \sum_j pr_{j,k} x_{i,j,k}$	(7)
	$DD_i = \sum_j DD_j x_{i,j,k}$	(8)
$\forall i,k$	$\sum_j x_{i,j,k} = 1$	(9)
$\forall j,k$	$\sum_i x_{i,j,k} = 1$	(10)
$\forall i,j,u$	$SA_{i,w,u} x_{i,j,u} \le SA_{j,w,k} x_{i,j,k} + M(1 - O_{i,j,k})$	(11)
$\neq k$	$SA_{i,w,u} x_{i,j,u} > SA_{j,w,k} x_{i,j,k} - M(O_{i,j,k})$	(12)
$\forall i,j,u$	$FA_{i,w,u} x_{i,j,u} \le FA_{j,w,k} x_{i,j,k} + M(1 - N_{i,j,k})$	(13)
$\neq k$	$FA_{i,w,u} x_{i,j,u} > FA_{j,w,k} x_{i,j,k} - M(N_{i,j,k})$	(14)
$\forall i,j,k$	$N_{i,j,k} + O_{i,j,k} \le 1$	(15)
$\forall i,j,k$	$\sum_k (N_{i,j,k} + O_{i,j,k}) \le 1$	(16)
	$N_{i,j,k}, O_{i,j,k}, x_{i,j,k}, \gamma_{i,k} \in \{0,1\}$	(17)

After modeling and determining the various aspects of the problem, different methods are employed to solve this problem. Since the problem is primarily from non-linear relationships whether in multiple objective functions and restrictions, and the variables are also different and on the other hand, many believe that the studies entail computational complexity class of NP-Hard, algorithms will be used for this purpose for achieving compliance efficiency as well as time rationality. Since this problem is a less focused configuration in the putrefying items literature, the innovative models for such a configuration are slightly applicable in the literature, where the problem is treated through population-based meta-heuristic algorithms. Therefore, the performance of the algorithm is studied through imperialist competition. The next stage explores hot to determine the algorithm briefly and then how to specialize the implementation with problem conditions.

Imperialist Competitive Algorithm

Imperialist competition is in fact the competitive countries to gain greater influence as well as more power to the survival of the scope of their reign. The power of an empire is defined as the power of a colonial country plus the percentage of the total power of colonies.

This algorithm will be introduced in the following flowchart:

Figure 1: Flowchart of algorithm

RESULTS AND DISCUSSION

Implementation and Results

The Imperialist Competitive Algorithm was design through MATLAB R2010a coding software and on a laptop with specs Intel®Core i7 2.00GHz and 8.00GB RAM and the Windows 7 as operating system, 64-bit.

Moreover, the summary of results and graphs for comparison of the performance of algorithms for all of the problems are as follows:

Moreover, the summary of results and graphs for comparison of the performance of algorithms for all of the problems are as follows:

Problem size			**Imperialist Competitive Algorithm**			**Lingo**
Activity	**Number of jobs**	**Number of machines**	**Worst solution**	**Mean**	**Best solution**	**Optimal solution**
Average	7	7	302	373	394	420
	5	8	224	224	227	
	6	3	225	225	225	
	6	6	212	265	283	
	6	6	211	212	215	
	5	3	240	341	360	
	6	4	200	208	213	
	6	4	245	259	267	
	6	8	200	200	202	
	5	4	200	203	207	
	7	6	201	278	281	
	7	6	223	248	311	
	7	5	326	381	389	
	6	8	221	225	226	
	7	6	238	287	324	
Large	9	9	223	322	363	
	8	9	277	280	382	
	8	11	223	223	225	
	8	9	345	346	383	
	9	11	322	322	327	
	8	9	213	218	219	
	9	9	201	239	255	
	7	10	293	297	309	
	8	11	380	392	392	
	9	9	331	332	393	
	7	12	224	227	231	
	7	12	345	364	395	
	8	11	275	316	392	
	9	11	264	283	297	
	8	10	227	252	360	

As can also be seen in the table above and in the following charts graphically, the three criteria best, worst and average solutions in imperialist competition algorithm are offered. However, since that was necessary to determine the validity of the model, an example (first example of small size) was solved by Lingo where the optimal value and the value of the imperialist competition were about 4% different, which is reasonable due to the random nature of the imperialist competition. Moreover, since a comparison

between the modeled and reality modes should be applied on the case study, the researcher obtained job report documents in the first example, compared the value based on the defined features and only mixed in the objective function, which was as compared to the manual calculation, approximately 321.2. This number represents the value was lower than the best value in imperialist competition algorithm (about 17 percent). Moreover, it was worse by about 25% than the model optimal solution calculated through Lingo. Therefore, it can be predicted that in other sizes there will be improved model.
Also, we have:

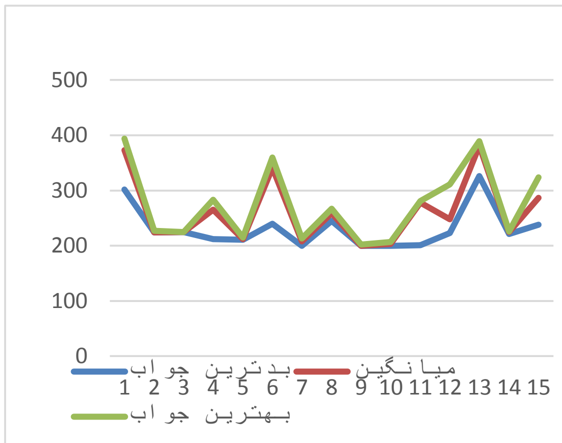

Figure 4-1: Comparing the performance of mid-sized algorithms

As can be seen, the above derived from previous table, suggests the random behavior of the algorithm, so that on some issues such as 2, 3, or 9 and 10, the best, worst and average solutions are completely identical, which indicates the local efficiency trap and in some cases such as No. 6 or 11 and 12 there is sufficient distance between the three worst, best and average solutions. Moreover, the fact that the average solutions are often close to the best solution indicates that the number of iterations of the algorithm for approximating the population of colonies and the imperialist societies are adequate.

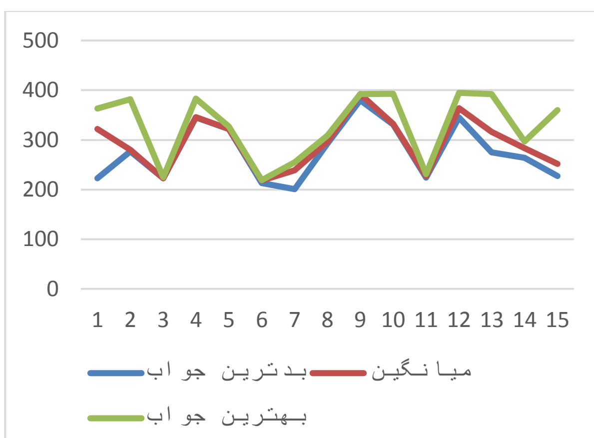

Figure 4-2: Comparing the performance of large algorithms

As can be seen, the above derived from previous table in large-scale, suggests the random behavior of the algorithm, so that on some issues such as 11 the best, worst and average solutions are completely identical, which indicates the local efficiency trap and in some cases such as No. 6, 2, 10 and 12 there is sufficient distance between the three worst, best and average solutions. Moreover, the fact that the average solutions are often close to the best solution indicates that the number of iterations of the algorithm for approximating the population of colonies and the imperialist societies are adequate.

Conclusions

According to models, this is the first time that some of the assumptions and certain configuration are used in this research where manufacturing and maintenance are considered together. Assumptions, algorithms and methods for comparing the performance of these algorithms could reveal some important tests in the area of this issue in both the manufacturing and maintenance. It can be argued that the scope and phasing of the work is such that it can be a major part of the route optimization process as well as the maintenance.

In this research, a model was used for the simultaneous determination of the scheduling of manufacturing and maintenance. The indicators such as level of service, time of service and the amount of MRO were presented based on measurable time and cost leading to a mathematical model. Moreover, its performance was evaluated through a real case study at Mashhad Subway so as to examine the key parts in service delivery (equivalent to manufacturing) to customers, by measuring parameters input to the model through a meta-heuristic solution. In such circumstances, the values mentioned in chapter four compared to the real situation suggest that when the model is not applied fully in the planning and MRO unit of the company, its validity and priority cannot be judged. However, the available evidence indicate that certain parts will entail regularization and improvement of the indicators in terms of objectives and limitations.

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