Devising a Model for Optimum Breakdown Maintenance Time

Vineet Gupta
Associate Professor,
Department of Mechanical Engineering,
M.M.U., Mullana, Distt.-Ambala (India)-133203

Abstract

In theIndustrializedDivisions, maintenance activitieshave a prodigious stimulus intention being incrediblestress for timely delivery of the products in throat cut modestmilieu.In the contemporary industries under study, multiplicityof precarious machines/equipment positioned. Out of these, Boilers are well-thought-out to be of the dominantprominence. Present study offers basis for breakdown maintenance time analysis to assign the boilers. Conversely, an optimal man and machine deployment will condense the total breakdown time further by allowing for diverse inter relationships between subsystems of boilers for breakdown maintenance. A goal programming model for optimum breakdown maintenance time is developed to appraise the assorted levels of the boiler subsystems maintenance work. The constraints in such model formulation are obtained by providing some priority based benchmark jobs. This model has been conceded out with having deviations in different situations with providing positive and negative variations in data.

***Key words**: Model, Breakdown time, Process Industries, India.*

1. Introduction

Production target of every industry depends largely on the performance of its machines and equipment [99]. However, performance of the machines and equipment are dominated by their design and maintenance system which is further dominated by various factors like manpower planning,expertise and allocation, selection of supporting machines, management of spare parts and overall time management. [25].

Maintenance Concept

Some of the definitions of maintenance are as under:

(1) The act of maintaining or the state of being maintained

(2) The work of keeping something in proper condition

(3) The combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function [17].

Breakdown Maintenance

Break down maintenance system is also known as Emergency repair system were repair work is carried only after the actual failure of the equipment. The equipment is allowed to run un-disturbed till it fails. Of course, lubrication and minor adjustments (pressure, flow etc.) are done during this period. Only when equipment fails to perform designed functions or comes to grinding halt, any other Maintenance/repair job is taken[24].

Goal Programming

Goal Programming is a technique/ approach to formulate the software to provide the multiple solutions. As under normal circumstances, many managerial decisions involve conflict and innumerable goals. It introduces complexity in decision making process. Thus, the goal programming is one tatteredtechnique to deal such difficulties [10].

2. Literature Review

Ahuja andKhamba [1] highlighted the achievements of an Indian manufacturing enterprise through strategic Total Productive Maintenance (TPM) initiatives. TPM implantation initiatives in an Indian manufacturing organization have been investigated to ascertain benefits accrued as a result of successful TPM implementation.

An et al. [2]developed two computer-aided tools as part of the Smart Plant Process Safety (SPPS) system. One is to help with the task of identifying hazards related to maintenance work and the other is to carry out cause and effect analysis automatically. This paper highlights the main functions of these two tools and describes how they are developed. It also illustrates how the cause effect analysis tool can be used to support hazard identification before carrying out the maintenance work.

Arora and Arora [4] observed that most of the problems on facility location are in reality multicriteria problems. In practice, facilities may have constraining capacities on the amount of demand they can serve. To bridge the gap between theory and practical, they have considered the multiobjective capacitated plant location problem. The multiobjective plant location problem is decomposed into two sub-problems. The allocation of plants to the clients when the capacities are restricted has been discussed in detail. Two algorithms are presented to solve the allocation problem.

Artana and Ishida [5] delivered a method for determining the optimum maintenance schedule for components in wear out phase. The interval between maintenance for the components is optimized by minimizing the total cost. Desai and Mital [8] have presented the basic concepts and an outline of current research in the field of designing products/systems to enable ease of maintenance and understood that most of the researches are reactive in nature and is not useful as far as design is concerned. A methodology that enables product design for maintenance is conspicuous by its absence. So, focuses on research efforts that can be directly helpful in the evolution of such a methodology.

Dreyer [9]suggested the Advance Maintenance Planning and Scheduling (AMPS) model to perform an integral role in reducing maintenance turnaround time and to increase the system availability. Also, discussed the maintenance planning and scheduling model that it is an effective method to leverage real-time health and status data of the mission system, significantly increasing maintenance productivity.

Huang [11] focused on this study to optimally coordinate the maintenance schedule of machines to save the maintenance cost incurred, which is named as the maintenance scheduling problem for a family of machines (MSPFM). Model and their heuristic were used for solving the MSPFM. Full analysis on the mathematical model for the MSPFM was conducted. By utilizing the theoretical results, proposed a new search algorithm that solves the optimal solution for the MSPFM very efficiently.

Jeong et al. [12] described an integrated decision support system to diagnose faults and generate efficient maintenance and production schedules of electronics manufacturing system. The proposed integrated system was composed of three modules, namely, the Diagnosis Module, the Maintenance Planning Module, and the Scheduling Module.

Lee et al. [16] addressed that how maintenance can be transformed from pure 'strategies' into 'a service function'. A state-of-the-art review on maintenance design is conducted and then a methodology and tools for effect predictive maintenance service design are presented. Two applications in the areas of closed-loop product life cycle management, and factory energy management, are discussed.

Nikolaos et al.[20] projected a maintenance system design framework and presents a successful implementation of the suggested design framework in a Greek manufacturing company. Oke et al. [21] have dealt with facility maintenance scheduling model which incorporates opportunity and inflationary costs. Panayiotou et al. [22] highlighted the significance of plant maintenance as profit generator for the corporation and developed a suitable maintenance concept. That concept had enabled the decision of specific maintenance strategies based on the existing situational factors to affect the functioning of the organization.

Waeyenbergh andPintelon[26] described the CIBOCOF framework to develop a customized maintenance concept in a specific company. Specific and new to this framework is that the optimization problem of maintenance is also taken into account. As such, Models described in literature finally find a way to practice, and the gap between theory and practice is closed a little bit in this paper; the framework is presented and illustrated by means of a case study.

Wenzhu et al. [27] proposed a sequential Condition-Based Maintenance (CBM) policy for intelligent monitored system based on cost and reliability prioritization. This maintenance policy differs from other policies in taking into consideration of influences from the frequency of maintenance activities and operating time on system's failure rate function subject to a deterioration process.

Kareem and Aderoba[13] developed a model for estimating the cost of maintenance gang(s) in maintenance systems utilizing salient factors such as interest and inflation, with the heuristics and real life functions. The cost of operating the gang is estimated using Activity-Based Costing (ABC) and it includes the cost of crew, tools/equipment, inventory, building, utilities among others. Ananda andMaiti [3] adopted the risk-based maintenance (RBM) approach to design an alternative strategy to minimize the loss resulting from these breakdowns or failures. The methodology consists of four modules: system definition, risk assessment, risk acceptance criterion and maintenance planning. In this study, the RBM approach was adopted for a gas expansion turbine of a steel plant.

Tsakatikas et al. [8] evolved a methodology and Decision Support System (DSS) for the establishment of spare parts criticality with a focus on industrial unplanned maintenance needs. The obtained criticality is used to rationalize the efficiency of the plant spare parts inventory. Chang [6] has proposed a new concept of level achieving in the utility functions to replace the aspiration level with scalar value in classical Goal programming (GP) and Multi-choice goal programming (MCGP) for multiple objective problems. According to this idea, it is possible to use the skill of MCGP with utility functions to solve multi-objective problems. Choi [7] described a new mathematical model of line balancing for processing time and physical workload at the same time by goal programming approach and designed an appropriate algorithm process for the operation managers to make decisions on their job scheduling efforts, whereas various computational test runs are performed on the processing time only model. Kharrat et al. [14] proposed an interactive optimization method for imprecise multiple-objective decision-making situations. The aim of the proposed approach is to integrate explicitly the decision-maker's (DMs) preferences within the interactive imprecise goal programming model. The DMs preferences will be expressed through the satisfaction functions concept. Kharrat et al. [15] adapted a record-to-record travel (RRT) algorithm with an adaptive memory named taboo central memory (TCM) to solve the lexicographic goal programming problem. The proposed method can be applied to non-linear, linear, integer and combinatorial goal programming. Because that the RRT has no memory, the adaptive memory TCM is inserted to diversify research.

Mezghani et al. [19] addressed an effective method to elaborate an aggregate plan which takes into account the manager's preferences by a Goal Programming (GP) approach, with satisfaction functions. Patia et al. [23] have formulated a mixed integer goal programming (MIGP) model to assist in proper management of the paper recycling logistics system. The model studies the inter-relationship between multiple objectives (with changing priorities) of a recycled paper distribution network.

3. ProblemFormulation

Breakdown Maintenance is selected for research work where existing maintenance system of boiler plant/equipment has been carried out. After in depth study in three different process industries, it is observed that the varieties of problems are arises in the boiler maintenance system like: improper allocation of maintenance manpower, absence of vital knowledge in performing the job, absence of knowledge sharing culture, absence of data base for staff competencies, dominating attitude of individuals due to their experience and position, absence of estimation of maintenance cost of any particular breakdown per under different prevailing conditions etc.

This study is focused on the time of any breakdown under different prevailing conditions, because timeconsumed by maintenance is increasing day by day which caused the increase in cost of the production. Because of this reason, Optimum breakdown maintenance time model based on preemptive goal programming approach is developedso that time incurred in any particular breakdown can be evaluated and future action plan can be framed to reduce the breakdown time and ultimately the production cost.

Some of the assisting equipment in these processing plants under study namely turbines, cane chopper, boilers, crystallizer, elevators, cane carrier, cane mincer, extraction mills, juice clarifier, centrifugal machines, hopper(drier), paper machines, pulp machines, chemical house, pulverized fuel mills, ash hopper, electro static precipitator, etc. are deployed for manufacturing the sugar whereas, the boilers are considered to be of the paramount importance.

Objective of the Study

To cultivate the Model for Optimum Breakdown Maintenance Time

To cut down the maintenance time contrariwise to diminish the production time

4. Model for Optimum Breakdown Maintenance Time

Present study offers basis for breakdown maintenance time analysis to assign the boilers for minimum maintenance time requirement to make the availability of these boilers is maximized in production. Conversely, an optimal man and machine deployment will condense the total breakdown time further by allowing for diverse inter relationships between subsystems of boilers for breakdown maintenance.

A preemptive goal programming model for optimum breakdown maintenance time is developed to appraise the assorted levels of the boiler subsystems maintenance work. The constraints in such model formulation are obtained by providing some priority based benchmark jobs.

Assumptions

Assumptions taken into consideration under the research work are as under:

a) Only breakdown maintenance problems are included in the study.
b) Cooling time of boilers is not considered as breakdown time.
c) Below eight man hours of breakdown time is treated as running maintenance.

Factors Influencing the Maintenance Time

Six factors are considered, those influence the maintenance time, which are given under the heads (J_i) as:

a) Job Quality (J_1)
b) Skill of the Workers (J_2)
c) Resource Items (J_3)
d) Supervision Quality (J_4)
e) Environment (J_5)
f) Teamwork (J_6)

For more critical analysis, each factor Ji (i = 1, 2... 6) is categorised under five different levels (j = 1, 2... 5) with respect to the complexity of maintenance job.

However, influence of these factors on the maintenance system may differ from breakdown to breakdown. In order to achieve the overall maintenance requirements, a model has been developed by grouping each of these factors to correspond to different complexity.

As presented in Table: 1, the ascending order of the levels in this table signifies the increasing complexity in maintenance jobs:

Table: 1: Factors Influencing the Maintenance

Factor J_i	Job Complexity Level 'j'				
	1	2	3	4	5
Job Quality	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}
Skill of Workers	J_{21}	J_{22}	J_{23}	J_{24}	J_{25}
Resource Items	J_{31}	J_{32}	J_{33}	J_{34}	J_{35}
Supervision Quality	J_{41}	J_{42}	J_{43}	J_{44}	J_{45}
Environment	J_{51}	J_{52}	J_{53}	J_{54}	J_{55}
Teamwork	J_{61}	J_{62}	J_{63}	J_{64}	J_{65}

The planning and allocation of manpower largely affects the functioning of the engineering section. The quality of maintenance work and the nature of its complexity should be duly considered in planning. In many situations, adequate skilled heads are not available commensurate with the total workload of the section. A poor quality spares or assisting equipment increases the maintenance time. Proper maintenance supervision would generally need comparatively lesser maintenance time, while a high degree of skill of the maintenance workforce may reduce the maintenance job completion time even when the supervision is inferior. Moreover, the working attitude of the maintenance team members influences the maintenance time considerably. It is needless to mention that a poor teamwork relationship would lead to an increased maintenance job time. Further, the working atmosphere for the maintenance group also plays a vital role in carrying out the task. Undoubtedly, a favourable working environment would increase the output of the workmen.

The influencing factor for quality of maintenance job (J_1) needs to be evaluated in regard to the breakdown maintenance time requirement for a particular boiler. The maintenance job of boiler has five subsystems as given below:

a) Feed Pump
b) Fans
c) Super Heater
d) Tubes
e) Miscellaneous

The breakdown of the boilers may happen due to the failure of any of these subsystems. Each such subsystem is further alienated into six sub- levels based on the requirement of maintenance time to be estimated as:

If a maintenance group is having manpower (n) deployed for a time (t) in hours to perform the maintenance job of a particular sublevel ($J_{jk)}$ then the job output ($T_{jk)}$ may be denoted as:

$$T_{jk} = n \times t \text{ hours}$$

Where, 'j' varies from 1 to 5 indicating each subsystem and 'k' varies from 1 to 6 indicating sublevels for each subsystem as shown in Table 2.

The maintenance time required for a sublevel of any subsystem is estimated by the time study method. It is assumed that the spare parts are always available at the store. Now the maintenance jobs of the Feed pump is identified by (J_{1k}) having J_{11}, J_{12}, J_{13}, J_{14}, J_{15}, J_{16} types of jobs corresponding to different job complexity level as per the requirement of the maintenance time. The maintenance times required for such different levels would correspond to the level wise job complexity i.e. needs for the least complexity job (J_{11}) is (T_{11}) hours and those for the highest job complexity would be (T_{16}) hours. Similarly, all the other subsystems are categorized as J_{2k} - Fans, J_{3k} - Superheater, J_{4k} - Tubes, J_{5k} – Miscellaneous.

Table 2: Boiler subsystems with job levels

Subsystem Job Level 'Jj'	Job Complexity Sub-Level 'k'					
	1	2	3	4	5	6
Feed Pump	J_{11}	J_{12}	J_{13}	J_{14}	J_{15}	J_{16}
Fans	J_{21}	J_{22}	J_{23}	J_{24}	J_{25}	J_{26}
Super Heater	J_{31}	J_{32}	J_{33}	J_{34}	J_{35}	J_{36}
Tubes	J_{41}	J_{42}	J_{43}	J_{44}	J_{45}	J_{46}
Miscellaneous	J_{51}	J_{52}	J_{53}	J_{54}	J_{55}	J_{56}

Let, C_{jk} be the cost of maintenance job for the j_{th} level of job complexity of k_{th} sublevel.

The total maintenance cost for a particular boiler under breakdown may be estimated as the sum of the costs (C_{jk}) corresponding to the individual job levels (J_{jk}) i.e. for the different combination of j and k. Thus, the total maintenance time for failures in various subsystems is the sum of all individual maintenance times.

Benchmark Jobs

The maintenance times for the benchmark jobs of the boilers are estimated in man-hours by time study. These benchmark jobs are having different constituent elements one each under a particular level of job complexity considering that all such elements having failed simultaneously. The selection of benchmark jobs are done on a random basis considering that the failures would be in all the five subsystems to help in evaluating the worth of the rest of sublevels, while the minimum and the maximum values are provided by the plant authorities. Now, the maintenance times for five benchmark jobs are estimated as:

$$T_{11} + T_{22} + T_{31} + T_{46} + T_{56} \leq 100 \text{ manhours} \quad \ldots (1)$$

$$T_{12} + T_{21} + T_{34} + T_{42} + T_{54} \leq 85 \text{ manhours} \quad \ldots (2)$$

$$T_{11} + T_{23} + T_{31} + T_{42} + T_{54} \leq 75 \text{ manhours} \quad \ldots (3)$$

$$T_{14} + T_{22} + T_{31} + T_{41} + T_{51} \leq 60 \text{ manhours} \quad \ldots (4)$$

$$T_{13} + T_{21} + T_{31} + T_{41} + T_{51} \leq 50 \text{ manhours} \quad \ldots (5)$$

It is implausible that the score structure in a maintenance system would fully satisfy the equations 1-5. However, these are the goals for each of the jobs and there may be some deviations arising out of the time study procedure and the structure of the maintenance system. Certainly, these should be permissible deviations for smooth functioning of the system. The other constraints for lower limit, higher limit and deviation between two consecutive sublevels are as such:

$$T_{j1} \geq 6 \text{ manhours} \quad \ldots (6)$$

$$T_{j6} \leq 25 + (5 \text{ X } j) \text{ manhours} \quad \ldots (7)$$

$$T_{jk} - T_{j(k-1)} \geq (4 + j) \text{ manhours} \quad \ldots (8)$$

For developing the model, equations 1-5 can be rearranged as below:

$$T_{11} + T_{22} + T_{31} + T_{46} + T_{56} - p_1 = 100 \ldots$$

$$T_{12} + T_{21} + T_{34} + T_{42} + T_{54} - p_3 = 85 \quad \ldots$$

$$T_{11} + T_{23} + T_{31} + T_{42} + T_{54} - p_2 = 75 \ldots (A)$$

$$T_{14} + T_{22} + T_{31} + T_{41} + T_{51} - p_4 = 60 \ldots$$

$$T_{13} + T_{21} + T_{31} + T_{41} + T_{51} - p_5 = 50 \quad \ldots$$

Where, p_1, p_2, p_3, p_4 and p_5 are the positive deviational variables.

The equation set (A) indicates that each level should be duly evaluated so that each individual equation must satisfy with a minimum value of deviation.

Apart from the deviations in score for the benchmark jobs, there would be some deviations also in relation to the individual score of a given job factor. Such constraints may be represented as:

$$\mathbf{T_{j1} + n_{j+5} = 6 \text{ manhours} \ldots (B)}$$

$$\mathbf{T_{j6} - p_{j+10} = 25 + (5 \times j) \text{ manhours} \ldots (C)}$$

$$\mathbf{T_{jk} - T_{j\,(k-1)} + n_{\{5(j-1)+(k+14)\}} = (4 + j) \text{ manhours} \ldots (D)}$$

a) The equation (B) shows that lowest value of maintenance job time T_{j1} for each level should be at least 6 manhours and negative deviational variables are associated with the constraints, while below this mark the jobs are to be done by the running repair groups.
b) The equation (C) shows that highest possible value of maintenance time for each subsystem and positive deviational variables are associated with these constraints. Such limit values would correspond to the highest job complexity and maintenance job time increases by 5 manhours from one job level to the other for the most complex job.
c) The equation (D) shows that the difference of manhours for any particular subsystem should include the negative deviational variables. The difference in maintenance job times for the consecutive sublevels is the same for any subsystem. When the subsystem level number gets increased, the difference of job times for the respective sublevels would also be increased by one manhour due to the complexity of work.

The achievement function of the goal programming model may be formulated as:

$$\text{Minimize, } Z = \{ P_1(\sum_{k=1}^{5} p_k), P_2(\sum_{k=6}^{10} n_k), P_3(\sum_{k=11}^{15} p_k), P_4(\sum_{k=16}^{40} n_k)\} \ldots (E)$$

subject to satisfying the constraints (A), (B), (C) and (D).

The equation (E) shows that Pi (i = 1, 2, 3, 4) indicate the priority levels that are assigned in respect of different sets of positive or negative deviational variables.

Analysis of the Results

The optimum values of T_{jk} as listed in Table 3 and the deviations from the goals presented in Table 4 are computed by solving the linear goal programming problem.

Table 3: Sublevel wise Optimum Breakdown Maintenance Time

Subsystem Job Level T_j	Job Complexity Sublevel 'k' (Man-Hours)					
	1	2	3	4	5	6
Feed Pump, T_1	6	11	16	21	26	32
Fans, T_2	7	12	17	22	27	33
Super Heater,	8	13	18	23	29	35
Tubes, T_4	9	15	20	25	30	38
Miscellaneous,	10	16	21	26	31	36

Table 4: Goal attainment for breakdown maintenance benchmark jobs

Benchmark jobs	Allotted score	Goal achieved	Goal Under achievement
1	100	100	0
2	85	82	3
3	75	72	3
4	60	60	0
5	50	50	0

It may be observed from Table 4 that for the benchmark jobs 2 and 3, there exist some negative deviations, whereas the allotted scores are just achieved for other benchmark jobs 1, 4 and 5.

5. Results and Discussion

Present research work is the development of a Model for Optimum Breakdown Maintenance Time to cut down the maintenance time contrariwise to diminish the production time, for different breakdowns of the boilers, whereas study is demeanour at nearby three processing plants.

To formulate the model, goal programming approach is used. The model is formulated by considering some priority based benchmark jobs, constraints, assumptions and major factors and by amending any one of the persuaded factors, the maintenance time also get altered. Conversely, these factors have been subleveled further for an awfully precise assessment of the most advantageous maintenance times with due regard to the complexity level of the maintenance jobs to be completed.

Thus, formulated Model has induced an assortment of pre-decided scores which are evident fromTable 4 that:

Merit of each of the benchmark jobs 1, 4 and 5 are conquered exactly the assigned score.

Merit of the benchmark jobs 2 and 3 have been below three points each to the assigned score.

Deviation in the score of the benchmark jobs is 6% from the total dispensed score.

Conclusion

The Model for Optimal Breakdown Maintenance Time for the boilers is formulated with the help of goal programming method. The developed model is within 6% variation of the designated benchmark jobs, which is satisfactory one.

Scope for Future Work

1. The present investigation has been focused only on boilers whereas the concept may be applied to other machines and equipment namely deployed at such plants.

2. Nonetheless, this study is exercised in three organizations and can be extended for possible application in other industrial sectors.

3. Although, integer technique is applied in the study, even, non-integer technique may be applied to get meticulous results.

References

[1] Ahuja, I.P.S. and Khamba, J.S. (2008), 'An assessment of maintenance management initiatives in the Indian manufacturing industry', International Journal of Technology, Policy and Management, Vol. 8, No.3, pp. 250 - 278.

[2] An, H.; Chung, P.; McDonald, J and Madden, J. (2009), ' Computer-aided identification of isolation boundary for safe maintenance and cause and effect analysis for assessing safeguards', International Journal of Process Systems Engineering, Vol. 1, No.1 pp. 29 - 45.

[3] Ananda, N. and Maiti, J. (2008), 'Risk-based maintenance of gas expansion turbines in steel plant', International Journal of Risk Assessment and Management, Vol. 10, No.1/2, pp. 147 - 159.

[4]Arora, S. and Arora, S.R. (2010), 'Multiobjective capacitated plant location problem', International Journal of Operational Research, Vol. 7, No.4, pp. 487 - 505.

[5] Artana, K.B. and Ishida, K. (2002), 'Spreadsheet Modeling of Optimal Maintenance Schedule for Components in wear-out phase', Reliability Engineering and System Safety, Vol. 77 No. 1, pp. 81-91.

[6] Chang, C.T. (2011), 'Multi-choice goal programming with utility functions', European Journal of Operational Research, Vol. 215, No. 2, pp. 439-445.

[7] Choi, G. (2009) 'A goal programming mixed-model line balancing for processing time and physical workload,' International Journal of Production Economics, Vol. 57 , No. 1, pp. 395-400.

[8]Desai, A. and Mital, A. (2006), 'Design for maintenance: basic concepts and review of literature', International Journal of Product Development, Vol. 3, No.1, pp. 77 - 121.

[9]Dreyer, S. L., (2006), 'Advance Maintenance Planning and Schedule', presented at Autotestcon, IEEE, pp. 341-347.

[37]Gupta, P.K. and Hira, D.S. (2010) 'Operations Research', S. Chand & Company Ltd., N. Delhi, pp. 33,568-574.

[10] Huang, J.Y. (2006), 'New Search Algorithm for Solving the Maintenance Scheduling Problem for a Family of Machines', Optimization Methods and Software, Vol. 21, No. 3, pp.461–477.

[11]Jeong, I. J.; Leon, V. J. and Villalobos, J. R. (2007), 'Integrated Decision Support System for Diagnosis, Maintenance Planning, and Scheduling of Manufacturing Systems', InternationalJournal of Production Research, Vol. 45, No. 2, pp. 267–285.

[12]Kareem, B. and Aderoba, A.A. (2008), 'A Cost Estimation Model of Maintenance Jobshop Operations', AU J.T., Vol. 12, No. 1, pp 25-33.

[13]Kharrat, A.; Chabchoub, H. and Aouni, B. (2010), 'Decision-maker's preferences modelling within the interactive imprecise goal programming model', International Journal of Innovative Computing and Applications, Vol. 2, No.3, pp. 150 - 169.

[14] Kharrat, A. ; Dhouib, S. and Chabchoub, H. (2010), 'Adaptive record-to-record travel method to solve lexicographic goal programming models', International Journal of Information and Decision Sciences, Vol. 2, No.2, pp. 147 - 169.

[15]Lee, J.; Chen, Y.; Hassan, A. A.; Ali, H.A. and Lapira, E. (2009), 'A systematic approach for predictive maintenance service design: methodology and applications', International Journal of Internet Manufacturing and Services, Vol. 2, No.1, pp. 76 - 94.

[16]Marquez, A. C. (2007), 'The Maintenance Management', Springer, London, pp. 1.

[17] Marquez A. C.; Gupta, J. N. D. and Ignizio, J. P. (2006), 'Improving Preventive Maintenance Scheduling in

Semiconductor Fabrication Facilities', Production Planning &Control, Vol. 17, No. 7, pp. 742–754.

[18]Mavrotas, G.; Georgopoulou, E.; Mirasgedis, S.; Sarafidis, Y.; Lalas, D.; Hontou, V. and Gakis (2009), 'Multi-objective combinatorial optimization for selecting best available techniques (BAT) in the industrial sector: the COMBAT tool', Journal of the Operational Research Society, Vol. 60, No. 7, pp. 906–920.

[19] Mezghani, M.; Rebai, A.; Dammak, A. and Loukil, T. (2009), 'A Goal Programming model for Aggregate Production Planning problem', International Journal of Operational Research, Vol. 4, No.1, pp. 23 - 34.

[20]Nikolaos A. Panayiotou, N.A. ; Stavros T. P. andSotiris P. G. (2009), ' Designing an industrial maintenance system: a proposed methodological framework', International Journal of Information Technology and Management, Vol. 8, No.4, pp. 361 - 381.

[21]Oke, S.A., Oluleye, A.E., Oyawale, F.A. and Charles - Owara, O.E. (2008), 'A facility maintenance scheduling model incorporating opportunity and inflationary costs',International Journal of Industrial and Systems Engineering - Vol. 3, No.4, pp. 423 - 466.

[22] Panayiotou, N.A.; Ponis, S.T. and Gayialis, S.P. (2009) 'Designing an industrial maintenance system: a proposed methodological framework', International Journal of Information Technology and Management, Vol. 8, No. 4, pp. 361–381.

[23] Patia, R.K.; Vratb, P. and Kumar,P. (2008), 'A goal programming model for paper recycling system', Omega, Vol. 36, pp. 405 - 417.

[24]Srivastva, S. K. (2005), 'Industrial Maintenance Management', S. Chand & Company Ltd., N. Delhi, pp 42-55.

[25] Tsakatikas, D.; Diplaris, S. and Sfantsikopoulos, M. (2008), 'Spare parts criticality for unplanned maintenance of industrial systems', European J. of Industrial Engineering, Vol. 2, No.1, pp. 94 - 107.

[26] Waeyenbergh, G. andPintelon, L. (2009), 'CIBOCOF: A framework for industrial maintenance concept development', International Journal of Production Economics, Vol. 121, No. 2, pp. 633-640.

[27]Wenzhu, L.; Ershun, P. and Lifeng, Xi, (2009), 'A condition-based maintenance policy for intelligent monitored system', International Journal of Computer Applications in Technology, Vol. 35, No. 2/3/4, pp. 104 - 112.