Relevance and Applicability of Multi-objective Resource Constrained Project Scheduling Problem

Review Article

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Abstract— **Resource-Constrained Project Scheduling Problem (RCPSP) is a Non Polynomial (NP) - Hard optimization problem that considers how to assign activities to available resources in order to meet predefined objectives. The problem is usually characterized by precedence relationship between activities with limited capacity of renewable resources. In an environment where resources are limited, projects still have to be finished on time, within the approved budget and in accordance with the preset specifications. Inherently, these tend to make RCPSP, a multi-objective problem. However, it has been treated as a single objective problem with project makespan often recognized as the most relevant objective. As a result of not understanding the multi-objective dimension of some projects, where these objectives need to be simultaneously considered, distraction and conflict of interest have ultimately lead to abandoned or totally failed projects. The aim of this article is to holistically review the relevance and applicability of multi-objective performance dimension of RCPSP in an environment where optimal use of limited resources is important.**

Keywords: project management; scheduling; resource-constrained project scheduling problem; multi-objective; performance measure.

I. INTRODUCTION

A recurring problem in project management involves the allocation of scarce resources to individual activities comprising the project. The International Standard Organisation (ISO)-8402 [1] defined the term "project" as "a unique process, consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements including constraints of time, cost and resources". The Project Management Institute (PMI) in their Project Management Body of Knowledge (PMBOK, 2008) [2] defined the term "project" as "a temporary endeavor undertaken to create a unique product, service, or result". However, no single definition of the term will meet or suit all cases. All projects have several attributes in common, namely: objective, uniqueness, complexity, temporary nature and uncertainty. In project-based management, the performance measure is usually centered on effective utilization of time, cost and resources required for a given scope of work. Project management involves planning, scheduling, monitoring and control of project activities to achieve project objectives.

Project scheduling deals with defining which activities are to be performed at a particular time. Sule [3] observed that scheduling involves the arrangement of activities to meet certain requirements, constraints, or objectives. In essence, scheduling is an optimization problem which primarily involves the allocation of resources (machines) to a number of tasks (jobs) such that one or more optimization criteria are met. In scheduling, the resources are characterized in terms of their qualitative and quantitative capacities. This means that resources are described by their type and number. The task is described in terms of its resource requirement, duration, start and finish time. The scheduling objective represents the measure of performance. The growing research effort in scheduling has led to a wide variety of problem types and the introduction of a classification scheme. Graham et al (1979) referenced by Leung [4] introduced the classification for machine scheduling problems which comprises of three fields $\alpha|\beta|\gamma$.

The α field specifies the machine environment. The β field provides details of the task and resource characteristics. The γ field denotes the optimality criteria (performance measures) and often contains a single objective. Demeulemeester and Herroelen [5] extending this classification to project scheduling, proposed a similar scheme. The aim is to allow a concise taxonomy of the project scheduling field. The project scheduling problem is characterized by precedence relationship between activities or jobs and the sequence of tasks is typically predetermined with an unlimited number of resources. This problem of scheduling project activities led to the discovery of the Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT) in 1959.

These techniques are based on the use of a network or graphical model that deals with time element of the schedule known as activity scheduling. The two methods assume the availability of all required resources (i.e. resourceunconstrained schedule) for a set of precedence-constrained activities in a deterministic environment. This can be denoted as shown in "(1)" where *P* represents unlimited resources, n is the number of jobs or tasks and the objective is to minimize the completion time or makespan (C_{max}) [6]:

$$(P\infty | n, precconst | C_{\max}) \qquad (1)$$

In project execution, the resources required can be human, machine, financial, material, etc. However, the availability of these resources is a major problem because it may be limited or constrained to a certain limit. Therefore, the use of CPM and PERT in situations where resources are limited becomes too idealistic for most real life problems of scarce resources. Hence, the problem of scheduling project network under resource constraint known as resource constrained project scheduling (RCPSP) emerged.

In reality, there are projects which are resource constrained but have to be strictly finished on time (time-related objective), within approved budget (cost-related objective) and in accordance with the preset specifications (quality-related objective). For example, a small and medium enterprise contemplating on introducing Advanced Manufacturing Technologies (AMT) in order to ensure high product quality and low product cost. Thomas et al [7] identified lack of clear guidance and project management knowledge as the major contributor for not embarking on such project. Although, other problems confronting small enterprises have been identified to include improvement in business quality, cost, time, quick return on investment, staff training and sticking to goals [8]. Another example is the construction of a residential building by a low income earner in which time, cost and quality objectives are ranked equally.

The resource constrained project scheduling is a problem for most project managers because virtually all organizations use their project schedule not only as a tool to manage their project, but also as a basis on which to deliver project objectives to clients. As a result of not understanding the multi-objective dimension of some projects, conflict of interest between project managers and project stakeholders have ultimately lead to abandoned and failed projects. This is because project stakeholders tend to measure the performance and success of their project using the original schedule submitted during the bidding process.

Viana and Pinho de Sousa [9] considered the RCPSP to be inherently a multi-objective problem thou it has been treated as a single objective problem. Based on this observation, we found that there is no article in literature focusing on the relevance and benefits of multi-objective RCPSP. Therefore, the aim of this work is to holistically review the relevance and applicability of single and multi-objective performance dimension of RCPSP. Special emphasis will be given to the application project management tools and techniques in Nigeria and sub-Saharan Africa.

This paper is organized as follows: Section two reviews the theoretical framework of RCPSP, the various optimality criteria and possible combination of project objectives. Section three considers the algorithms for solving single and multi-objective RCPSP. Section four considers project management in Nigeria. Section five concludes.

II. LITERATURE REVIEW

The RCPSP is a classical problem in operation research with broad applicability in project management. The problem was first identified by Pritsker et al. [10]. Pinedo [6] described the problem as:

$$m | n, precconst | C_{\max} \qquad (2)$$

where m represent limited resources, n is the number of jobs or tasks, *precconst* identify the precedence relationship between tasks and the objective (C_{max}) is to minimize the completion time or makespan. Kolisch and Hartman [11] denoted the RCPSP as:

$$m,1 \ / \ CPM \ / \ C_{max} \qquad (3)$$

This means activities with finish- start precedence relationship and zero time lags have to be scheduled on *m* renewable resource types such that the maximal completion time of all activities (C_{max}) is minimized. Blazewicz et al. [12] further described the RCPSP as a generalization of the Job shop scheduling problem that belongs to the class of Non-Polynomial hard type optimization problems (NP-hard).

In general term, the RCPSP considers the limited capacity of resources and how to assign job/ activities to resources in order to meet predefined objectives. The problem is characterized by scheduling project activities subject to precedence and resource constraints. Usually, the resource constraints impose a limit on resource usage in one or more time periods of the project execution. As far as the resource categories are concerned, three types of resources are identified: renewable resources, which are renewed from period to period (e.g., machines available per day); non-renewable resources, these resources are available on a total project basis (e.g., money and energy) and doubly –constrained resources, which share the characteristics of renewable and non renewable resources [5].

The resource constrained project scheduling problem (RCPSP) can be stated thus: A project is represented by acyclic graph where nodes represent the activities and arcs represent the finish-start precedence relationship with zero time lag. Let *J* denotes a set of activities (jobs) to be scheduled where *J* = {I,….n} with *K* ={ I,….k} set of renewable resources types. The activities which are numbered from *I* to n mark the initial and final activity of the project and are assigned dummy status. The activities are constrained as follows:

- The precedence constraint forces each activity *j* to be scheduled after all the preceding activities to *j* are completed.

- Executing the activities requires resources with limited capacities

The following parameters are characteristics of the RCPSP as shown in Table 1.

TABLE I. CHARACTERISTICS OF RCPSP

Parameter	Definition	Remark
$r_{j,k}$	Activity j requires r units of resource type k	$k \in K$
$r_{1,k}$	Resource usage at the start of project	$r_{1,k} = r_{n,k} = 0$
$r_{n,k}$	Resource usage at the end of project	
dj	Duration of activity j	$d_1 = d_n = 0$; d_1, d_n are dummy activities
d_1	Duration for project start	Non-preemptable, Deterministic
d_n	Duration for project end	
F_j	Finish time of activity *j*	
$A(t)$	Set of activities being processed at time instant *t*	
k	Resource type k	Renewable type; Non-negative
R_k	Limited capacity of resource k at any point in time	

From the parameter identified above, the conceptual model of single objective RCPSP is described in "(4)" [13]:

Objective function: $Min \quad F_n$ (4)

subject to (constraints) :

$fn - dn \geq fi \qquad (1,n) \in J$

$\sum r_{j,k} \leq R_k \qquad k \in k; t \geq 0$

$J \in A(t)$

$F_1 = 0 \qquad j = 1.....n$

The objective function is to minimize the finish time of activity n. The first constraint effects the precedence relations between activities; the second constraint limits the resource type *k* demand by the activities being processed at time *t* to the capacity available. The last constraint assign a zero completion time to the start activity that is dummy.

A. Project Scheduling Objectives

The γ field in the project scheduling classification denotes the optimality criteria. This field often contains a single objective. These objectives are the criteria by which the performance of a solution procedure can be measured. Oyetunji [14] commented on the little study carried out so far on scheduling objectives. This is because scheduling objectives is complex, conflicting in nature and most times it is difficult to adequately state these objectives [15,16]. The possible combination of time, cost and quality based scheduling objective is a good example of the conflicting nature of scheduling objective.

The performance measure can either be regular or non-regular. Common examples of regular objectives include the makespan, lateness, tardiness, no of tardy jobs while non-regular objectives include the net present value (NPV),earliness penalty and weighted earliness-tardiness. Mellor [17] referenced by Oyetunji [14] identifies Beenhakker (1963) as the only author that highlighted about 27 distinct scheduling goals. For the project scheduling problem, Demeulemeester & Herroelen [5] identified some common performance measure and their component as discussed in Table 2.

B. Components of Resources in Project Scheduling

There are projects where time, cost and quality are equally weighed. In such situation, the "CPM thinking" is weakened and project managers will have to think in terms of a mix of objectives. The multi-objective thinking in RCPSP allows for overall consideration of all constraints found relevant for the successful execution of a project. Also, in an environment where resources are limited, a multi-objective approach will have less total cost than independently considering individual constraints [18]. Usually, the integrated model developed from a multi-objective approach will be harder than the problems from a single objective approach. Dodin and Elimam [18] identified components of resources available in project scheduling as shown in Table 3.

TABLE II. PERFORMANCE MEASURES AND THEIR COMPONENTS

Performance Type	Components	Remarks
Time	$\gamma = C_{max}$	Minimise the project makespan
	$\gamma = F$	Minimise the average flow time over all subprojects or activities
	$\gamma = L_{max}$	Minimise the project lateness
	$\gamma = T_{max}$	Minimise the project tardiness
	$\gamma = early / tardy$	Minimise the weighted earliness – tardiness of the project
	$\gamma = n_T$	Minimise the number of tardy activities
Resources	$\gamma = \sum sq.dev$	Minimise the sum of the squared deviations of the resource requirements from the average.
	$\gamma = \sum jump$	Minimise the weighted jumps in resource usage for all resource types over all time periods.
	$\gamma = \sum abs.dev$	Minimise the sum of the absolute deviations of the resource requirements from the average.
	$\gamma = av$	Minimise the resource availability in order to meet project deadline
	$\gamma = rac$	Minimise the resource availability costs i.e. the weighted availability of each resource type.
Cost	$\gamma = npv$	Determine the complete time/cost trade-off curve
Quality	$\gamma = Q$	Maximize quality by minimizing both estimated rework times and costs

TABLE III. COMPONENTS OF RESOURCES IN PROJECT SCHEDULING

Resources	Components
Material Planning	Ordering cost Holding Cost of material Holding Cost Completed activities Consumption rate per period Purchase price and quantity discount
Human Resources	Selection and cost of the desired skill level Overtime and regular cost Cost of temporary hires or consultants needed for the project Transition cost between activities and between projects
Equipment planning	Set up Cost Buy or lease options Overall and per period availability Impact of activity duration on equipment cost Transition cost between activities and projects

C. Single Objective RCPSP

The performance measure of RCPSP common in literature is the completion time or *makespan*. The makespan usually represent various concerns on accomplishing deadlines and maximizing the customer service. Minimizing project duration ensures that resources (machine, equipments, manpower, etc) for project activities are released promptly thereby making them available for use by other projects in the future. Also, it reduces the risk of violating a deadline and generates timely incoming cash flows. Viana and Pinho de Sousa [9] addressed the makespan as a "global measure".

Goldratt (1997) cited by Demeulemeester and Herroelen [5] commented that delays in project delivery are heavily penalized than budget overruns. Hewlett-Packard, for example, studied a high-growth market and found that if a new product innovation project would be getting to market six months later than originally scheduled, profits would reduce by 33%. But if going over the budget by 50% during the product development to ensure that the project was completed on time, profits would be reduced by 4% [19]. A critical look at this example shows that it violated the characteristics of a resource constrained project scheduling. This is evident by the willingness to overrun project cost by 50%. This reduces the problem to a *CPM-case* where resources are assumed to be unlimited. Thou, in project execution, budget overruns are clearly visible and attributable. This is an explicit choice of top management to speed up project delivery (by approving overtime, purchase of extra resources, etc).

D. Multi Objective RCPSP

The multiobjective RCPSP (MORCPSP) usually contains not a single solution that minimizes all the objectives simultaneously. The aim is then to find a set of solutions where at least one of the objectives is better than the others: the *nondominated (Pareto of efficient)* set [9]. In this case, one solution

y dominates x if $f_k(y) \leq f_k(x)\ \forall k$ and $f(y) \neq f(x)$

such that if there is no other feasible solution that dominates *x*, the solution *x* is *nondominated*. The multiobjective combinatorial optimization can be formulated as follows:

$$\min f(x) = \{f_1(x), \ldots, f_0(x)\}, f_k(x) = c_k(x) \quad (5)$$

subject to:

$x \in D$

where c_k is a vector $(1 \text{ X} n)$,

$x = [x_{1 \ldots \ldots} x_n]^T$ which represents the vector of binary decision variables

D the space of feasible solutions

In literature, some notable references were found for bi-objective case of RCPSP. Al-Fawzan and Haouari [20] addressed the issue of a bi-objective RCPSP. They considered the objectives of the robustness maximization along with the makespan minimization. Abbasi et al. [21] addressed bi-objective resource constrained project scheduling to minimize the makespan and to maximize the robustness aiming at the float time maximization in order to make scheduling more reliable. Kazemi and Tavakkoli-Moghaddam [22] considered a bi-objective multi-mode resource constrained project scheduling problem with positive and negative cash flows. Their first objective is maximization of the net present value (NPV) and the second is to minimize the makespan and floating time (i.e. maximization of robustness). The Net Present Value (NPV) analysis in project management is used among others to determine whether a project should be selected and in the planning and scheduling of projects with long durations [18]. The NPV analysis is also useful for cross-borders projects.

For multi-objective RCPSP, Viana and Pinho de Sousa [9] considered three objectives in their model: to minimize the makespan, minimize the mean weighted lateness of activities and minimize the sum of the violation of resource availability. Also, for the multidimensional RCPSP, Dodin & Eliman [18] proposed the integration of the components of time, cost and quality on what they called the "Totally Optimized Project System (TOPS)". The TOPS can be stated a follows: "Determine the start and finish time of project activities (including duration), the material ordering and inventory policies, and the allocation of human resources and equipment to these activities in order to minimize the total cost of the project or to optimize other selected measures of performance". They argued that their integrated project scheduling problem will have less total cost than independently considering this objective in a single objective problem. A critical look at TOPS shows that the authors did not consider the impact of limited resources as clearly identified in RCPSP. A consideration of the tri- nature of project objective (time, cost and quality) allows for a multi dimension approach to achieving the overall objective where resources are limited.

Despite the various works dealing with multiobjective resource-constrained project scheduling problems; Ballestin & Blanco [23] revealed that there is no theoretical study in the literature that establishes the fundamentals for correct algorithm development for the multi-objective RCPSP. Another gap in multiobjective RCPSP is lack of studies focusing on the development of solution procedures for problem with more than two objectives where the composite objective is a combination of different objective functions (regular and non-regular performance measures). This is an area where the authors are currently working on.

III. SOLUTION TECHNIQUES FOR SINGLE AND MULTI-OBJECTIVE RCPSP

Due to the increased interest in the RCPSP over the past decade, a vast amount of literature has appeared on different algorithms for solving both single and multiobjective problem types. For the single objective type, focus on the project duration minimization has led to the development of various exact methods and (meta-) heuristic procedures. Exact methods (or optimizing algorithms) return a provable optimal solution, whereas heuristic methods return a "good" solution that does not necessarily need to be an optimal solution. Exact methods are guaranteed to find a solution if it exists, and typically provide some indication if no solution can be found. While exact solution methods are able to solve smaller problems, they typically take too long (i.e. mostly non-polynomial time) when the problem size grows or when additional constraints are added. Hence, exact methods only suit small-scale problems and are not utilized for practical applications. Akbari et al [24] identified exact methods proposed by Mingozzi et al. (1998), Specher (2000) and Stork & Uetz (2005) as the most represented exact methods.

In solving the RCPSP, when the number of activities is large and the planning horizon is long, the RCPSP is usually solved using heuristics and metaheuristics, which can provide relative effective solutions. Heuristic methods typically require far less time and / or space than exact methods. The heuristics specify how to make a decision given a particular situation and contains rules for deciding which action to take. Heuristics in scheduling are often referred to as scheduling rules or dispatch rules. The definition of these rules is often quite complex, and most are tailored for a specific type of problem with a very specific set of constraints and assumptions. Most of the heuristics methods used for solving resource- constrained project scheduling problems either belongs to the class of priority rule based methods or to the class of metaheuristics based approach [25]. Many metaheuristics methods, such as Genetic Algorithms (GA), Simulated Annealing (SA), Tabu Search (TS), Scatter Search, Electromagnetism (EM), Immune Algorithm (IA) , Filter and Fan (FF) , Particle Swarm Optimization (PSO) and Ant colony optimization (ACO), have been proposed and applied to solve the RCPSP [24, 25]. Akbari et al [24] identified authors that exploited the advantages of two or methods to design a hybrid algorithm for better performance. Notably are ANGEL (Tseng & Chen, 2006), ACOSS (Chen et al., 2010), Neurogenetic (Agrawal et al., 2010), Scatter Search –FBI (Debles et al., 2006), and Hybrid – GA (Valls et al., 2008).

Oyetunji [14] identified three approaches for solving bi-criteria problems. These are: pareto-optimal, hierarchical and simultaneous minimization approaches. The pareto-optimal approach involves finding the set of all pareto-optimal schedules. The hierarchical minimization involves ranking the criteria in order of importance. The simultaneous approach aggregates the two criteria into a single objective. It is worthy to note that multi-objective metaheuristics versions of Genetic Algorithms (GA), Simulated Annealing (SA) and Taboo Search (TS) have been developed. Viana and Pinho de Sousa [9] applied the multiobjective metaheuristics version of Simulated Annealing and Taboo Search to solve a multi objective RCPSP. Their results reveal that a multi- objective approach is reliable and efficient way of solving RCPSP. This is because it enables the development of scheduling model which is flexible and reveals reality. Ulungu (1994) referenced by Viana and Pinho de Sousa [9] commented that "the adaptation of metaheuristics to a multiobjective environment is certainly one of the more promising research directions".

IV. PROJECT MANAGEMENT IN NIGERIA

Project Management allows the organization and integration of resources to achieve a specific goal within a designated time frame. Successful project management delivers the agreed outcome within an agreed quality, without overrunning its budget and delivery duration and crucially, achieving for the organization the benefit for which the benefit for which the investment in the project was made. Most developing nations of the world quest for economic development; this is evident in the commitment of governments in developing countries to withdraw from direct provision of infrastructures and the consequent emergence of public-private partnerships (PPP). As a result, Nigeria and many countries world-wide have adopted a project delivery approach wherein government agencies can act as enablers to private sector driven investment projects. The aim is to embark on a number of infrastructural projects that will deliver integrated social, economic, and environmental benefits.

A number of projects being delivered through Public-Private Partnership (PPP) in two states (Lagos and Ogun) in Nigeria are identified in table three. Project management tools and techniques were being used in the implementation of these projects. This information is obtained from random selection of economic bulletins made generally available to the public by the federal government. Majority of these projects started in 2008 and their current status is shown in Table 4.

In Nigeria, we can make the following general observations about projects:

- A majority of public, individual and public-private projects run beyond their budgets and due-dates.
- The Public-Private Partnership (PPP) often face cutoff of funding from foreign partners if the project progress is not completed on time.
- Resources are limited and optimal use of available resources is prevalent.
- A Presidential Projects Assessment Committee (PPAS) submitted a report in May, 2011 which identifies 11,886 ongoing and abandoned federal capital projects that will require N7.78 trillion Naira ($49.6 billion dollars) [26]. All the identified projects are estimated to be completed in eight years. The committee identified lack of direction in project management as one of numerous problems. This had lead to dotting the landscape in various parts of the country with uncompleted projects.
- Predominant use of Gantt chart (based on CPM) for project scheduling.

From the above mentioned characteristics of project management in Nigeria, the resource constrained project scheduling problem fits into the Nigeria case.

TABLE IV. EXAMPLE OF PPPS IN TWO STATES IN NIGERIA

Collaborators	Title	Focus	Current Status
OAU/NUC/UNESCO Partnership Workshop	Workshop on strengthening the capacities of Universities in Science and Technology Policy and Innovation Mgt	Training and Capacity Building	In progress
Ogun/Ondo State Government, Chevron, Shell and British Gas	Development of Olokola Liquefied Natural Gas (OKLNG)	Oil and Gas Development	In progress Change of democratic Government that initiated the project
AFC, Ogun-Ondo State Government	Seaport Development	Seaport Development	Abandoned Change of democratic Government that initiated the project
Consortium Company and Ogun State Government	Agro Cargo Airport Development	Airport Construction and Management	Change of democratic Government that initiated the project Abandoned
Lagos State Government and Consortium of Banks	Concession of Lekki- Ajah Expressway	Road / Highway Construction	Completed
Lagos State Government and Consortium of Banks	Concession of Ojoo – Badagry Expressway	Road / Highway Construction	In progress
Guangdong Company and Ogun State Government	Igbesa- Ogun State Free Trade Zone development	Free Trade Zone Development	In progress No clear direction
Ipem, Ogun-Ondo State Government	Olokola Free Trade Zone	Infrastructure Development and free trade Zone	In progress, Change of democratic Government that initiated the project, No clear direction
Ministry of Transport, Nigeria and Chinese Construction Company (CCC)	Lagos – Kano Railway Development	Transportation Development	In progress

V. CONCLUSION

In this paper, we review the project scheduling problem. The review emphasizes the resource constrained project scheduling problem (RCPSP). We confirmed that the most common performance measure of RCPSP in literature focuses on minimizing the makespan. We emphasized that there are situations where individual or corporate projects with limited resources have to be finished on time, within the approved budget and in accordance with the preset specifications. In such situations, the *CPM logic* (assuming the existence of unlimited resources) is weak. In practice, project managers tend to think in terms of a mix of objectives. This tends to make single objective approaches in RCPSP generally idealistic. This is not saying that early research focusing on single objective are irrelevant; such studies had tremendously helped to gain more insight into understanding and solving multi-objective RCPSP. We identified few research gaps in the study of multi-objective RCPSP. We identified that there are no solution procedures for solving the multi-objective RCPSP where the composite objective is a combination of regular and non regular objective function. This is an area we are currently working on. Also, the study highlighted different algorithms so far developed for solving single and multi –objective RCPSP. We highlighted the characteristics of project management in Nigeria and identified gaps. In summary, the multi-objective approach in practical situations was found to be the natural way of solving RCPSP.

REFERENCES

[1] International Standards Organisation (ISO) /CD 8402-1, Quality concepts and technology part1: generic terms and definitions, International Organization for Standardization, 1990

[2] Project Management Institute (PMI), A guide to the project management book of knowledge, Project Management Institute, Newton square, PA, 2008

[3] D.R Sule, Industrial scheduling. PWS Publishing Company, Boston, MA, 1997

[4] J Leung, (Ed), Handbook of scheduling: algorithm models and performance, CRC Press LLC; Florida. 2004

[5] E. L. Demeulemeester, W. S. Herroelen, Project scheduling: a research handbook, Kluwer Academic Publisher; Boston. 2002

[6] M. Pinedo, Scheduling: theory, algorithms and systems, Springer, New York, Third Edition, 2008

[7] A. Thomas, R. Barton, P. Byard "Technology implementation in manufacturing SMEs: a model for change". I*PROMS Virtual International Conference on Intelligent Production Machines and Systems, 2007

[8] A. Gunasekaran, L. Forker, B. Kobu "Improving operations performance in a small company: a case study" International Journal of Operations & Productions Management, Vol. 20, No. 3, pp. 316-335, 2000

[9] A. Viana, J Sousa, "Using metaheuristics in multiobjective resource constrained project scheduling" European Journal of Operational Research , 120, pp. 359- 374, 2000

[10] A. Pritsker, B. Allan. L.J Watters, P.M Wolfe, "Multiproject scheduling with limited resources: A zero-one programming approach", Management Science, Vol. 16, pp.93-108, 1969

[11] S. Hartmann, R. Kolisch "Experimental evaluation of state–of–the–art heuristics for the resource–constrained project scheduling problem", European Journal of Operational Research, Vol. 127, pp. 394–407, 2000

[12] J. Blazewicz, J. K. Lenstra, K. Rinnooy, "Scheduling subject to resource constraints: Classification and complexity", Discrete Applied Mathematics, Vol. 5, pp. 11-24, 1983

[13] N. Christofides, J. M. Alvarez-Valdes J. M. Tamarit, "Project scheduling with resource constraints: a branch and bound approach", European Journal of Operational Research, Vol. 29, pp.262-273, 1987

[14] E. O. Oyetunji, "Some common performance measures in scheduling problems: review article", Research Journal of Applied Sciences, Engineering and Technology, Vol. 1, No. 2, pp. 6-9, 2009

[15] S. French, Sequencing and Scheduling, Ellis Horwood Limited, 1982

[16] J. Albert, L. C. Rabelo, Survey of job shop scheduling techniques, NISTIR, National Institute of Standards and Technology, Gaithersbury, MD, 1998

[17] P. Mellor, "Review of job shop scheduling", Operations Research, Vol. 17, No. 2, pp. 161-171, 1966

[18] B. Dodin, A. A. Elimam, "Project Management: Challenges and Opportunities", Available online: www.mes.eg.net/ acrobat_files /1_2pdf: Accessed–June 4th,2011

[19] R. Suri, Quick Response Manufacturing: A companywide approach to reducing lead times, Productivity Press , 1998

[20] M. A Al-Fawzan, M. Haouari, "A bi-objective model for robust resource-constrained project scheduling, International Journal of Production Economics", Vol. 96, pp.175 -187, 2005

[21] B. Abbasi, S. H. Shadrokh, J. Arkat, "Bi-objective resource-constrained project scheduling with robustness and makespan criteria", Applied Mathematics and Computation, Vol. 180, pp. 146-152, 2006

[22] F. Kazemi, R. Tavakkoli-Moghaddam, "Solving a multi-objective multi-mode Resource-constrained project scheduling problem with particle swarm optimization", International Journal of Academic Research, Vol. 3, pp. 103-110, 2011

[23] F. Ballestin, R. Blanco, "Theoretical and practical fundamentals for multi-objective optimization in RCPSP, Journal of Computers and Operation Research, Vol. 38, No. 1, pp. 51-62, 2011

[24] R. Akbari, V. Zeighami, K. Ziarati, "Artificial bee colony for resource constrained project scheduling problem", International Journal of Industrial Engineering Computations, Vol. 2, pp. 45-60, 2011

[25] A. Sprecher, Resource-constrained project scheduling: exact methods for the multi-mode case". Lecture Notes in Economics and Mathematical Systems, Vol. 409, 1994

[26] "Jonathan worries over N7trillion Uncompleted projects", Thisday Newspaper, Friday, June 3rd, 2011. Available online: thisdaylive.com/articles/jonathan-worries-over- n7tr-uncompleted-projects/92555/ : Accessed–June 4th,2011Mallat, A wavelet tour of signal processing, Academic Press, 1999