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# Planned Preemption for Flexible Resource Constrained Project Scheduling

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The classic resource constrained project scheduling problem (RCPSP) schedules non preemptive activities while minimizing total lead time of project. There is always a need for tradeoff between resource allocation and project lead time minimization. This paper reveals the benefits of allowing preemption when scheduling activities in a resource constrained project. The focus is on analyzing the impact of preemption on project length under the condition of constant resource availability. The paper deals with comparison of the models for planned preemption in first part and provides a framework for reducing uncertainty due to unplanned preemption. The model provides an opportunity for flexible schedule with help of monitoring and control system.

**Keywords**: Makespan, Project Scheduling, Preemption.

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## 1. Introduction

Complexity and the challenging nature makes resource constrained project scheduling problem very popular in project scheduling area. There is a tradeoff between resource allocation and project lead time minimization. This tradeoff reveals the challenging nature of the problem. Moreover uncertainty in availability of resources adds to complexity of the problem. A project management problem typically consists of planning and scheduling decisions. . It involves careful planning of the activities, provision of necessary resources for the execution of tasks, proper sequencing of the activities. The planning decision is essentially a strategic process and includes planning for requirements of several resource types in every time period on planning horizon. Various parameters like technological, temporal and precedence constraints have to be considered while scheduling the activities for optimal resources usage. Project scheduling involves sequencing and execution of certain set of tasks, called activities, in predefined order on timeline. It aims at optimal allocation of scarce resources over time horizon. Scheduling involves decisions regarding job selection for execution at a particular point of time whereas the sequencing involves the order in which different tasks or activities are performed. The actual resource required at each stage is calculated along with completion time of each activity. In reality project resources are always scarce and needs to be managed properly. The unavoidable changes in the plan affect overall schedule and progress of the project. The scarcity results in unavoidable changes in the plan. As a result schedule gets disturbed affecting overall progress of the project. These interruptions are termed as pre-emption i.e. an activity can be interrupted in between and the same activity can be performed later. The additional cost for performing the activity later are considered zero.

Herroelen (1996) stated that preemption had little effect unless variable resource availability levels are considered. Vanhoche (2007) has extended branch and bound algorithm for preemption case of resource constrained project scheduling problem (PRCPSP). He has also introduced the concept of fast tracking coupled with PRCPSP for makespan minimization problem. This paper presents the PRCPSP to find the impact of pre-emption on makespan. There is no study that provide any framework to reduce random pre-emption resulted from the uncertainty in the project. This paper intend to put forth a model so as to reduce uncertainty and provide an opportunity for flexible scheduling. The outline of the paper is as follows. In section 2 an extensive literature review for RCPSP is done. In this section various types of RCPSP are discussed accompanied by solution approaches. The pre-emption case for RCPSP is discussed and comparison of existing models is presented. In section 3 the proposed model for planned pre-emption along with solution approach for problem is presented. Finally in section 5 conclusions is presented.

## 2. Literature Review on RCPSP

RCPSPs have been an area of interest for many researchers since 1950's. RCPSP is a subset of project scheduling in which the constraints are added for resources. The complexity of the RCPSP is due to execution modes and the time of activities, possibility of overlap of precedence, preemption of task, requirement of multiple resources, the reusability and variability of usage of resources. Brucker (1998) has described the RCPSP as problem to allocate the available resources to activities so as to find the shortest duration of a project (makespan) within the constraints of precedence relationships.

The project scheduling problem can be broadly classified as single project and multi project depending upon the sharing of the resources among more than one project. Activity duration is either deterministic or probabilistic. This gives way to classification based on environment. The tasks can be executed in a single mode when only one way of execution is available or in multiple modes when there are more options available for execution. Depending upon the number of resources utilized, RCPSP can be classified as single or multi resource RCPSP. Depending upon the objective function the RCPSP can be classified as regular or non regular objective function RCPSP. Obtaining an optimal solution is difficult for any real life RCPSP due to computational complexity. This motivated researchers to develop heuristic based solution approaches to solve these classes of problems. RCPSP classification is shown in figure 1.

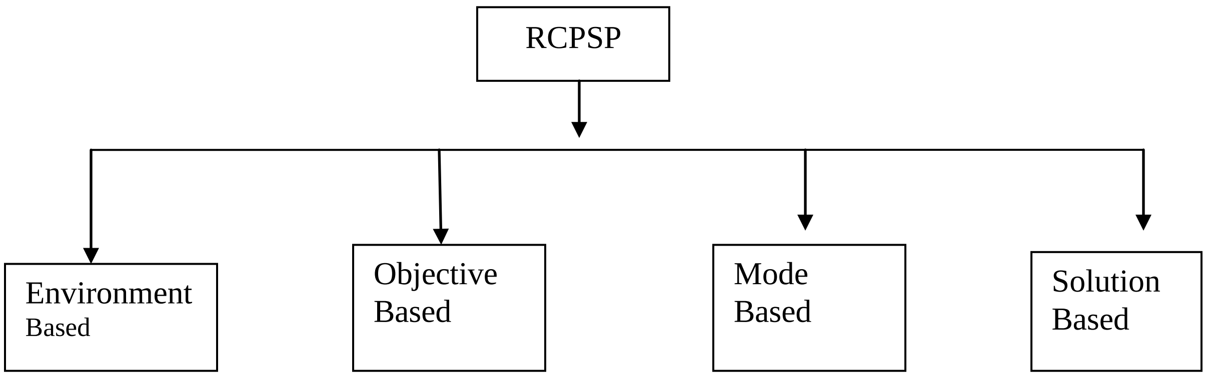


**Figure 1:** Classification of resource constrained problems

Kolisch (1996) has proposed new efficient priority rule to solve the makespan minimization problem. Traditional priority rules do not reflect the finite capacity of resources clearly. The new priority rule was an attempt to overcome the limitation of traditional rule. Nudtasomboon *et al*. (1996) have developed a zero-one integer programming model to find minimum duration schedule considering preemption, for renewable as well as non renewable resources. They have also considered time cost tradeoff. Herroelene *et al*. (1998) have reviewed literature on RCPSP and found that well designed depth-first branch and bound algorithm are suitable for solving RCPSP. Brucker *et al*. (2000) had compared different solution approaches for makespan minimization, with precedence constraint and NPV (Net present Value) maximization. Brucker (2000) has developed linear programming (LP) formulation and constrained propagation technique for makespan minimization. He has compared two lower bound calculation techniques and found LP gives better result compared to constrained propagation.

Brucker and knust (2003) extended the LP model for multi mode case and considered minimal and maximal time lags. Goncoalves, *et al*. (2007) have proposed genetic algorithm, to solve the same problem, for multi project.

RCPSP with preemption case has been studied in recent past with the assumption that preemption will improve the quality of solution. Herroelen, (1996) extended the RCPSP to PRCPSP (Preemptive Resource Constrained Project Scheduling Problem) and found that PRCPSP problem is more complex than RCPSP due to subdivision of activities and without any improvement in the objective function. Vanhoucke and Debels, (2008) have proposed a model based on preemptive concept and used branch and bound algorithm proposed by Herroelene (1996). They have found that preemption do affect the makespan. They had also introduced the concept of fast tracking (parallel scheduling) with planned preemption among sub activities and studied the impact of fast tracking on makespan. Vanhoucke (2009) has studied the impact of set up times on PRCPSP. However, an assumption of no setup cost was assumed. Peteghem and Vanhoucke (2010) had considered PRCPSP with multimode for makespan minimization. These models help us analyze the impact of preemption on makespan as well as resource utilization. However models discussed hardly propose ways and means to minimize occurrence as well as the impact of unplanned preemption.

Vanhouche (2008) proposed model for various activity assumption. The results for preemption case and fast tracking are stated below. The results show the improvement in makespan in comparison with RCPSP as well as PRCPSP proposed by Demeulemeester and heerolene (1996).

**3. The proposed Model.**

The proposed model aims at reducing the uncertainty of achieving the objective of makespan minimization in case of occurrence of preemption. Scarcity or unavailability of resources can lead planned preemption if the information about resources is available during planning stage.

Due to sudden change in the availability of resources, during execution preemption is considered. When the occurrence of preemption is sudden, it is termed as unplanned preemption.

In this paper, an attempt is made to manage unplanned or unexpected preemption. The model is developed to reduce the uncertainty of such cases and move it towards planned ones. The RCPSP with preemption is formulated as follows. The project is represented as activity on node network G (N, A) where N denotes set of activities and A denotes set of pairs of activities between which finish-start precedence relationship with minimal time lag of 0 exists. The notations used to develop the mathematical model are

n = number of activities in a project

N = Set of activities {1, 2,...n}

k = number of resource types

$d_i$ = duration of activity i

$S_i$ = start time of activity i

$S_j$ = start time of activity j, where j > i.

R = set of resources and defined as R = 1, 2 …k

$r_{ik}$ = the amount of resource type k that is required by activity i

$a_k$ = the total availability of resource type k

t: time duration , $t \in 1,\dots S_{n+1}$

P = Set of activities in process in the time period t

The mathematical model for RCPSP can be formulated as follows:

Min. $S_{n+1}$ (1)

s.t.

$S_i + d_i \leq S_j \quad \forall\, (i,j) \in A$ (2)

$\sum_{i \in P} r_{ik} \leq a_k \; \forall\, k \in R$ (3)

$S_0 = 0$ (4)

$S_i \in int^{+} \quad \forall\, i \in N$

Equation (1) gives the objective function of makespan minimization, i.e. minimizing the start time of n+ 1 th activity. Equation (2) gives the precedence constraint whereas Equation (3) gives resource constraint. Equation (4) states that project start at instance zero.

To consider preemption, we assume that activities can preempted at any time and restarted later on at no additional cost.

Each duration unit v of an activity i is assigned a starting time $S_{iv}$ where $v \in \{0; \ldots; di-1\}$. The RCPSP with preemptive problem can be formulated as follows:

Min. $S_{n+1,0}$ (5)

s.t.

$S_{i,di-1} + 1 \leq S_{j,0} \quad \forall\, (i,j) \in A$ (6)

$S_{i,v-1} + 1 \leq S_{i,v} \quad \forall\, i \in N, \forall\, v \in \{0; \ldots; di-1\}$ (7)

$\sum_{i \in P} r_{ik} \leq a_k \; \forall\, k \in R$ (8)

$S_{0,0} = 0$ (9)

$S_i \in int^{+} \quad \forall\, i \in N$

Equation (6) ensures that earliest start time of activity j is less than the finish time for last unit of duration of its predecessor i and equation (7) ensures that start time for every time instance of activity must be at least one time unit larger than the start time for previous unit of duration. Both this equation gives the constraints while preemption of activity as well as dividing them into sub activities for parallel scheduling. Equation (8) gives resource constraint while (9) ensures project start at instance zero.

### 3.1. Solution Approach

Let us consider a project consist of 9 nodes activities. The figure 2 gives AON network along with the time duration ($d_i$) and the resources ($r_{ik}$) required for each activity where it is assumed that there is only one resource type, k =1. Nodes 0 and node 9 are dummy start and end nodes respectively. Both resources and time duration is assumed to be 0 for dummy nodes. Also maximum availability of resource ($a_k$) is assumed to be 6 units in each time period. Given that only the activities 4 and 5 can be preempted

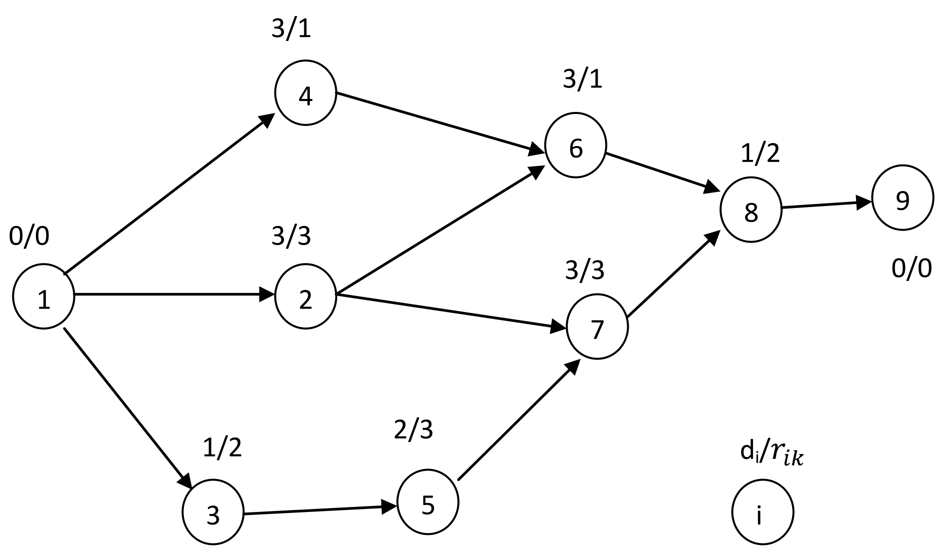


**Figure 2:** An example of AON network of project A.

The initial feasible solution without preemption for the project is shown in figure 3. The project can be completed in 9 time units.

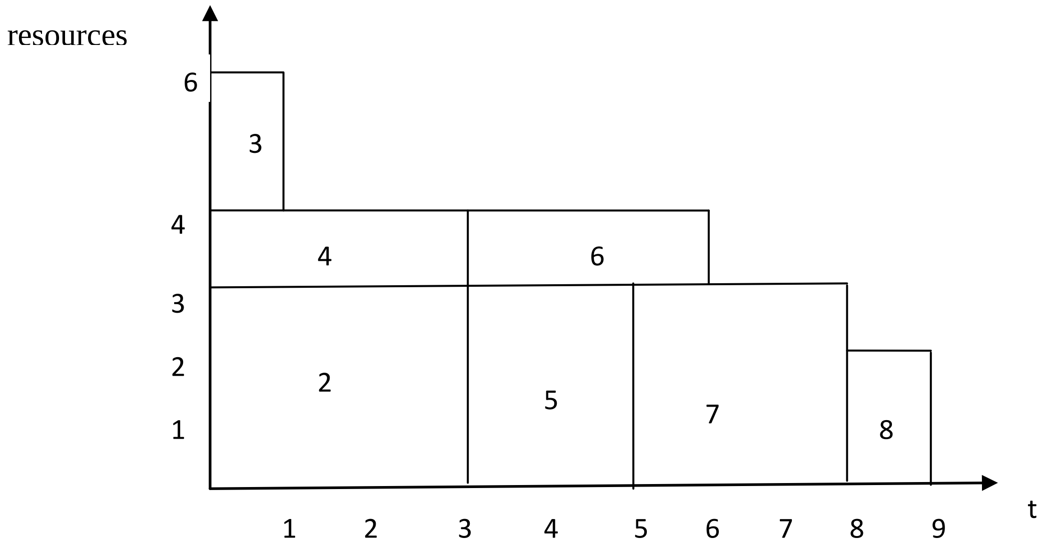


**Figure 3:** Initial feasible solution for project A.

Now, consider a case where the resources are not available, all of a sudden due to some reason at time period t=1. The time period t=1, the activities in process are 2, 4 and 3. Among them only 4 can be preempted. We schedule only 4a and postpone 4b.When activity 4 is preempted; it is replaced by activity 5a. Figure 4 clearly explain the preemption and reschedules. We schedule 5a at t=1 and delay 5b untill resource is available again.

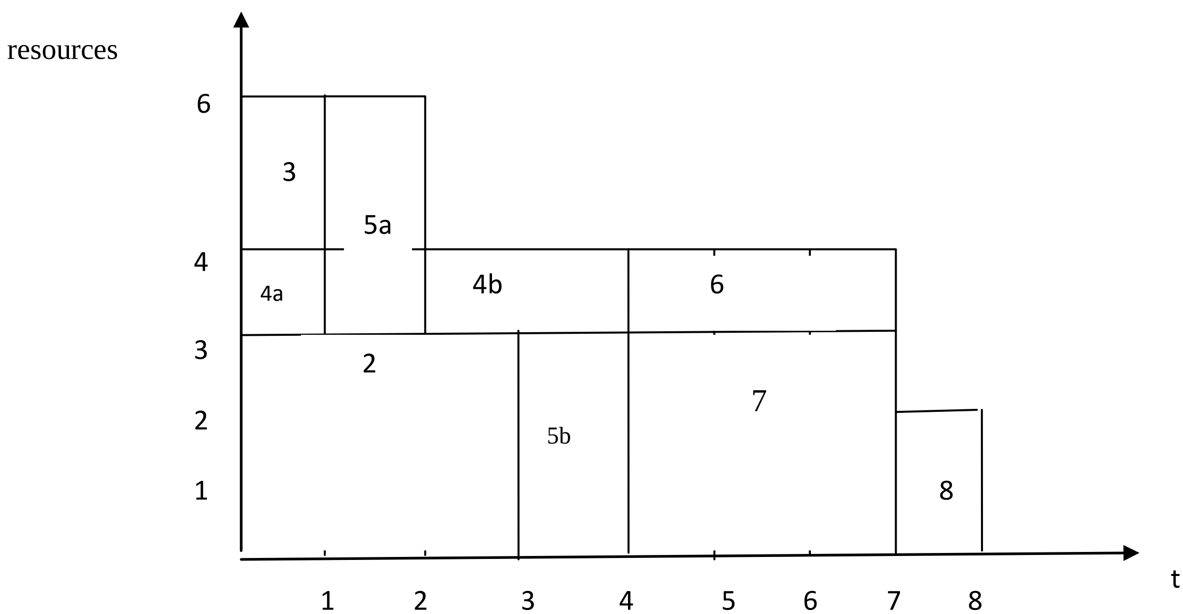


**Figure 4:** Final Solution for Project A with preemption.

The benefit of PRCPSP is twofold, first it manages the scarcity of resources and secondly it helps reduce total time duration by 1 time unit. Thus the makespan is now 8 units instead of 9. Here time duration is reduced by one unit however the complexity is increased.

We obtain master schedule for makespan minimization using any of the project management tool MS Project. Depending upon the nature of the activities they are categorized as those which can be interrupted and those which can’t be interrupted e.g. concrete pouring. The resource availability tracking helps to foresee unavailability of resources. If the resource availability for (n+1) th period is scarce then preemption occurs at nth period and the remaining activities are scheduled accordingly. Those activities which are independent and can be executed in parallel are rescheduled to reduce idle time or increase resource utilization.

Figure 5 gives the flow chart for solution approach. The initial feasible schedule is generated using standard PM software and checked for resource constraint violation. In such case, activities are preempted and then again scheduled. Activities are functional after a delay until availability of resources. In parallel with the scheduling of preempted activities, independent activities are also scheduled separately. This helps reduce idle time in case of independent activities. Also preemption helps best utilize the time delay and reduce makespan. At each activity, the availability of resources is checked so as to reduce the uncertainty due to scarcity of resources. The problem in figure 2 follows the solution approach of the flow chart. The activities for which preemption and sub division increase the complexity will fall under non preemptive activities. The notations followed in the flow chart are same as defined above.

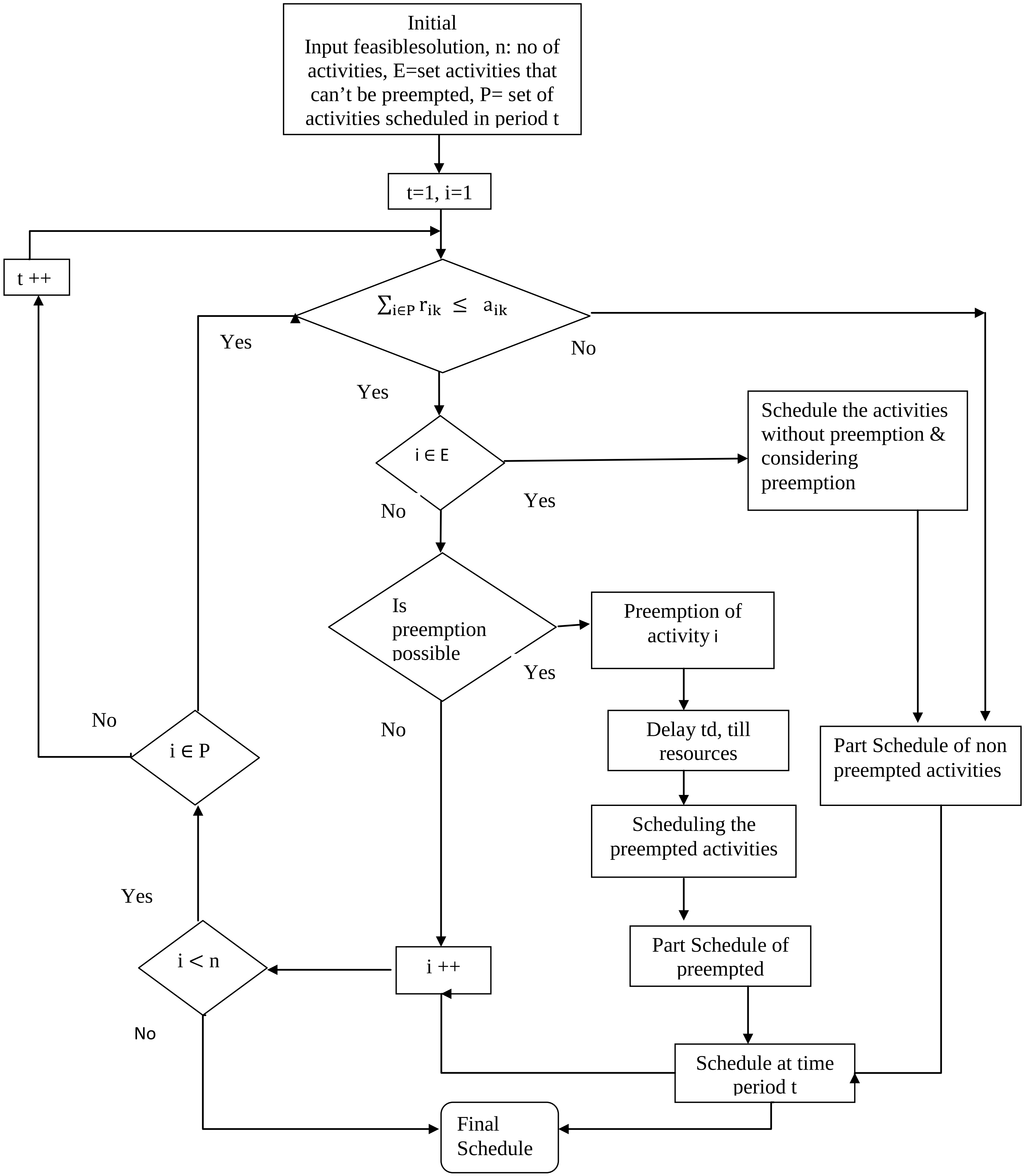


Figure 5: Flow Chart for Solution Approach

## 4. Conclusions

Classical project scheduling problems have not considered preemption of activities. Unavailability or scarcity of resources demands the interruption of activity and competitive pressures to complete project in minimum time have directed attention of researchers to see the effect of preemption on makespan. Preemption along with fast tracking has been analyzed using branch and bound methods as well as genetic algorithms for multi project case. It is reported in literature that planned preemption had no impact on makespan. But if implemented along with parallel scheduling it helps in makespan reduction of the project.

In this paper we presented a conceptual model for RCPSP with unplanned and unscheduled preemption. The model aims at reducing the impact of unplanned and unscheduled preemption. A different approach of usefulness of preemption can help develop efficient schedules. The interest lies in developing the preemption case in areas of scheduling considering resource constraints, with the help of solution approaches available. The objective is to reduce uncertainty of interruption due to resource unavailability or scarcity. This model shall help shift of unplanned preemption towards planned ones. In addition, structured and systematic way of handling unplanned situations of interruptions is proposed. The model also helps reduce idle time by allowing scheduling independent activities.

Preemption increases complexity and hence a trade off needs to be made between complexity and makespan objective. The model gives a method so as to achieve makespan goal while bearing with scarcity. We intend to extend these models for multimode as well multi projects.

Also the model needs to be tested using PSLIB problem dataset for various instances. Subactivity duration is considered to be one unit, increasing the complexity, increasing the complexity of the network. There lies scope in developing alternative means for deciding subactivity duration, so as to reduce the complexity.

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