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Scheduling Limited Resources in Engineering Projects

Samer Ben Issaa
Schulich School of Engineering, Department of Mechanical and Manufacturing Engineering, University of Calgary, Canada

Yiliu Tu
Schulich School of Engineering, Department of Mechanical and Manufacturing Engineering, University of Calgary, Canada

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Samer Ben Issaa[1], *Yiliu Tu*[1*]
[1]Schulich School of Engineering, Department of Mechanical and Manufacturing Engineering,
University of Calgary, Canada

Abstract: Because of high customizations in the one-of-a-kind production companies (OKP companies), these companies need to find a way for reducing the production cost, shortening the production lead-time, and maintaining the quality of the productions as in the mass production system MP.s. Currently, production scheduling in OKP system follows the traditional mass production system, which focus on time and inventory, and it is inapplicable. Actually, OKP system works based on customer requirements, where each order can be representing as multi-project based. In this paper, One-of-a-kind production OKP has been referred as a project-based production and as a flexible resource- constrained project scheduling problems (FRCPSs); because in practice, some of project activities cannot be pre-determined due to its high customizations and great uncertainties. A new model has been proposed based on these assumptions to create production schedules for OKP system, which focuses on time and resources as in project management system PM. s, and deals with the problem which have three categories of project activities A, B, and C. The per-findings indicated that the model enhances the applicability of resulting schedules, emulates what a project manager in practice does (i.e. adding or removing resources from tasks to have the project completed in time), increase the number of feasible solutions, and reduces the project duration.

Keywords: one-of-a-kind production system OKP. s, Flexible Resource-constrained project scheduling problem FRCPSP, Mass production system MP. s, Project management system PM.s.

1. INTRODUCTION

The classic version of the resource constrained project scheduling problem (RCPSP) normally consists of one mode. An Activity duration and resource quantity required must be predetermined for each project activities, and normally they are non-preemptive. The typical aim of the RCPSP is to create a schedule that minimizes the total project duration, subject into two constraints: 1) precedence constraint, which means an activity cannot be started until the preceding activities in the project network are finished (finish-start relationship with zero-time lag); and 2) resource availability constrain, which means resources are limited during the execution of an activity period. The time constraints are caused by the relationships between each activity and the durations of the activities. Resource constraints rise from the relation between the availability of a resource type at a given time and resource required of all activities being executed at that time. Meanwhile, each activity in Multi-mode Resource-Constrained Project Scheduling Problems (MRCPSP) can be accomplished in one out of several modes, which means an activity in RCPSP has been extended by allowing several alternatives (modes) in which an activity can be performed. Each mode reflects a feasible way to combine an alternative duration with different levels of resource requirement to accomplish the activity (i.e. project activities can be pre-planned into one or more running modes). Moreover, resources assignment over the activity duration in (RCPSP) and (MRCPSP) are normally constant. In the RCPSP & MRCPSP, there are two different activity categories have been considered: 1) Category A, which referred to non-preemptive activities with constant resources profile (CRP) as depicted in Figure (1A): Project activities are displayed as rectangular shape, where X-axis represents the duration of the activity (5), and Y-axis represents the resource required per time unit (2), and 2). Category B, which referred to preemptive activities with constant resource profile (CRP): Activities can be executed by several different ways as depicted in (Figure 1B).

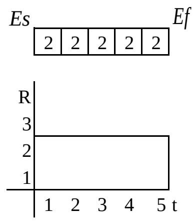

Figure 1A. Non-preemptive activity executes by constant resource profile (CRP-RCPSP).

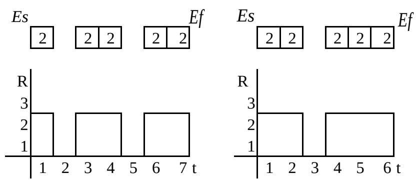

Figure 1B. Preemptive activity executes by constant resource profile (CRP-MRCPSP).

The RCPS problems have been well documented, and they have been gained high attention. Meanwhile, there are several models have been proposed to find the best solution for MRCPSPs [1]-[2]-[3]-[4]. MRCPSP is NP-hard problem, and if there are at least two non-renewable resources, the problem of finding a feasible solution is already NP-complete [20]. Genetic algorithm presented for the preemptive and non-preemptive resource constrained project scheduling problem[7], a model formulation and solution method for RCPSP established where assumed that the project structure should be provided in advance[8], and lastly, Branch and Bound model (B & B) modified to solve MRCPSPs by allowing activities to be splitting[9], and a new criterion called Minimum Moment Of Resource Required around X-Y axes (MMORR) has been used to find the best feasible solution as indicated in (Figure 2). However, none of the previous models can be used for solving large-sized projects in reasonable computation time (the number of project activities which have been used in these models are less than 100 activities [10]), and they used only two categories of activity.

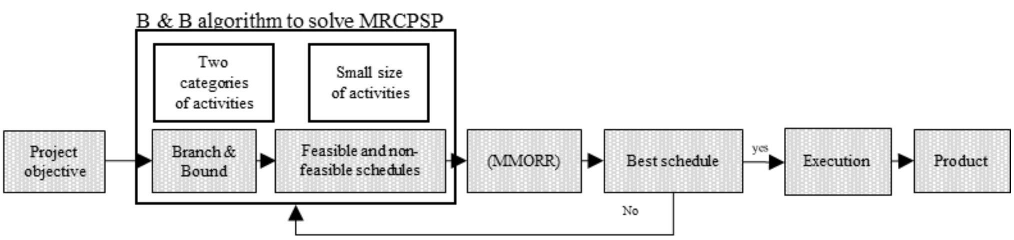

Figure 2. The B & B model used to solve MRCPSPs.

The MRCPS problem has been extended, where the activities can be classified into three categories as follows:1) Category A; Non-Preemptive activities with a constant resource profile (CRP); 2) Category B; Preemptive activities with a constant resource profile (CRP); and 3) Category C; Preemptive or non-preemptive activities with Flexible Resource Profile (FRP), which means variable units of resource (Y-axis) may work on an activity in each time unit due to expected or unexpected reason, and they can freely split along time duration (X-axis) during the execution as are depicted in (Figure 3a, 3b, 3c and 3d) as examples. In such a case, the total amount of resource required to complete an activity over its duration must at least satisfy its resource required. This type of project activities is in general characterized and defined by a work contents [11], e.g. person-day or man-hour…etc. The number of resource units allocated to execute an activity of this category usually may vary over execution-time. Consider e.g. the example in (Figure 3) which corresponds to a work content of 10 resource - time units; this task can be processed within 10-time units by one resource unit (1x10) each day as illustrated in (Figure 3a) , or can be processed by several other ways such as (1x3, 2x2, and 3x1), (3x2, 1x2, and 2x1), or (2x1, 3x2, and1x2) as illustrated in (Figure 3b, 3c, and 3d) respectively.

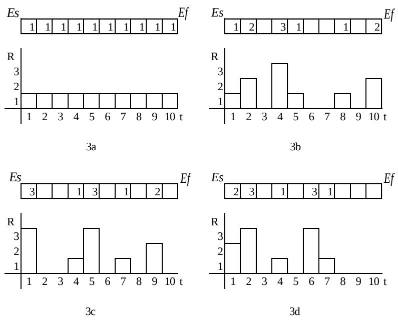

Figure 3. FRP-Activity executes by using a flexible resource rate (FRCPSP).

Defining the work-content per activity and resource type is quite similar to the MRCPSP but adds greater flexibility during the scheduling process. In the latter category, neither resources usage nor activity duration are known. The problem called MRCPS problem with flexible resources (FRCPSP), which is easy to define, but so difficult to solve. The FRCPSP deals with a set of N activities which must be scheduled by somehow to minimizing project duration, subject to: 1) Precedence constraint; 2) Resources available during the project execution are limited; 3) Splitting activities is not allowed; 4) Minimum block length constraint, which means that there must be at least a number of a consecutive period having a constant resource usage; 5) Maximum and minimum resources profile confining the resource allocation per time to be within a specific range; 6) Synchronization for resource allocation to each activity[12].

The resources required by an activity are classified into three types: 1) A principle resource is the resource which used as basis for other resources to process the activity; 2) A dependent resource is the resource which its use dependent on its principle resource; And 3) An independent resource is a resource whose allocated quantity is independent from any other resources.

They are sorted as follows; 1) Renewable resources which are available in limited quantities during each unit time; and 2) Non-renewable resources which are limited for the entire project.

A hybrid metaheuristics model proposed for FRCPSPs where for each activity the given resource requirement is allocated in a variable number of period during the activity execution [6], and the resource constrained project scheduling problem addressed with flexible resource profile where each activity may start, end or change its resource allocation at any point of time [12]. However, in the practice, Project Manager deals with the following project scheduling problem: Some of project activities, that are pre-planned and specified as non-preemptive activity with (CRP) as category A, some other project activities are pre-planned and specified as preemptive activities with (CRP) as category B, and the rest of project activities are assumed and specified as work content and have to be processed by the work-content resource (FRP) as category C. Thus, the new model deals with the problem which have three categories of project activities A, B, and C, assumes that each activity in category C could be splitting during the execution. In this paper, we will refer the One-of-a-kind production (OKP) as a Project-based production, and as FRCPS because some of the project activities cannot be predetermined due to its high customization and great uncertainties. The per-findings indicate that the model enhances the applicability of resulting schedules, emulates what a project manager in practice does (i.e. adding or removing resources from tasks to have the project completed in time), increase the number of feasible solutions, and reduces the project duration.

The remainder of the paper is organized as follows. Section 2 provides the literature review. While section 3 describes the problem statements. Section 4 illustrates the methodology. Section 5 addresses numerical example, and section 6 conclusion.

2. LITERATURE REVIEW

The first studying for the flexible Resource-Constrained Project Scheduling Problem (FRCPSP) was in 2006 in the context of real-world application in pharmaceutical research and development projects and deals with the lead optimization phase of pharmaceutical research where a number of leads (molecules as a basis for potential drugs) are proposed by different department in order to optimize their biochemical [13]. The project scheduling problem with work-content constraints formulated as a mixed-integer linear program for small instances to assess an existing method [16]. A procedure has been proposed to find all feasible work profile of each project activity instead of a fixed duration and resource requirement, the total work content is given, and using genetic algorithm to schedule activities [17]. A priority-rule scheduling method proposed to develop a feasible serial schedule-generation scheme and to determine a feasible resource-usage to each period. The usage of the work-content resource can be varied between a lower and an upper bound and must be integer [11]. Mixed-integer linear program MIP-based heuristic proposed to schedule the activities sequentially. The heuristic starts by ordering the activities in a precedence-feasible list, the activities are then scheduled one at a time. Each time a prescribed number of activities has been scheduled, a subset of activities is rescheduled. The inefficient resource allocation can be reduced by considering multiple activities simultaneously in the rescheduling phase [18]. Mixed-integer linear programming formulation presented to solve the FRCPSP and to show that the problem can be solved efficiently for small and medium sized instances using a commercial solver [19]. A hybrid metaheuristic HM to solve the FRCPSP has been proposed, the best schedules are improved in a variable neighborhood search by transferring resource quantities between selected activities. The HM consists of a genetic algorithm GA combined with a variable neighborhood search [6]. Four discrete-time model formulation for the FRCPSP presented and investigate the model efficiency in terms of problem size, solution quality, and runtime [15]. A mixed-integer linear programming model proposed to solve FRCPSP, using the continuous-time system to synchronize activities and resources [14].

In short, to the limit of our knowledge, none of all the papers mentioned above have assumed that there are three categories of activity A, B, and C (Preemptive, Non-Preemptive, and flexible resource profile activities) to solve the multi-resource constrained project scheduling problems as is in OKP activities.

3. PROBLEM STATEMENT

In this paper, a project consists of $V=\{1,......n\}$ activities as well as dummy source activity 0 and dummy sink activity $n+1$ to be scheduled. The activities are categorized to be $(A, B, \text{and } C)$, where category A is defined as activities that must be executed by assigning constant resource profile (CRP), and activities splitting is not allowed, category B is defined as activities that must be executed by assigning constant resource profile, and activities splitting is allowed, and category C is defined as activities that can be executed by assigning flexible resource profile and activities splitting is allowed. For category $A \text{ and } B$; durations and resources required are known in advance, while they are unknown in category C. The work-content that essentially represents how much of work has to be applied for executing an activity in category C should be considered. The One-of-a-kind production (OKP); is a production system to produce customized products within a product domain, which means productions are characterized by product designs that change with every order. Usually the quantities are small or just one. The characteristics of OKP.s can be summarized as:

- Great uncertainties in production control.
- High customization.
- Complicated and dynamic production system.
- Creating production schedule and control is extremely difficult.
- Production planning and scheduling is represented as multi-project schedules and sometimes is represented as a mega project scheduling problem, and that is because of the daily large numbers of the customer requirement.
- A one-of-a-kind production (OKP) system is a Flexible Manufacturing System with lot size of one [21].

Currently, production scheduling in OKP system focuses on time and inventory. It follows the traditional mass production system. OKP system works based on customer requirements, where each order can be representing as multi-project basis. Meanwhile, customer expects these orders to be delivered in shorter time and at nearly the same cost as mass production with high quality. Projects manager have been tried to apply production schedules of mass production system in OKP system. However, those production schedules are inapplicable because of resource constraints that imposed on the project. Moreover, project management system has been applied mainly for civil constructions because it focuses on time and resource constraints. Thus, OKP system can be considered as project management system because its production-schedules focus on time and resource constraints too. As a result, the objective of this research is how to create the production schedules of

PM.s in OKP.s, reduce the variable cost of customized production system (OKP), shorter the lead-time, while maintaining the same quality level. Therefore, creating a fast method or an algorithm to speed up the setup times of scheduling and rescheduling the production in OKP companies from time to time can be effectively way to achieve these goals (customer satisfaction). The engineering efforts usually take the major part of the variable cost in this type of production system, and one of these efforts is process planning and production scheduling and control [21]. (Figure 4) demonstrates the effects of applying the model proposed on customer satisfaction and what are the benefits expected comparing with other production systems (i.e. use the production schedules of PM. s in the OKP.s).

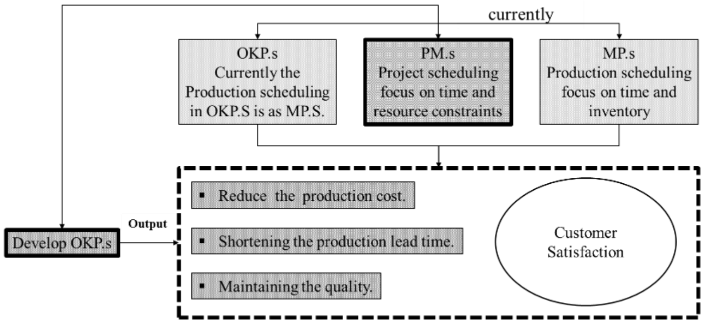

Figure 4. The customer requirements by applying the model proposed

4. METHODOLOGY

A new model has been addressed the OKP projects, which represents as Resource-Constrained Project Scheduling Problem with Flexible resources (FRCPSP) for determining the starting time, resource profile, and activity duration in order to minimize project duration, with allowing activities to be splitting as indicated in (Figure 5). In OKP projects, there are some activities can be pre-determined and executed as are indicated in (Figure 1A & 1B), and some others can be pre-determined as work content and can be executed by different ways as indicated in (Figure 3). Due to high customization and grate uncertainties in OKP, Project manager should find an effective algorithm to schedule these three-different types of activities to obtain a best feasible solution out of several other solutions. To put it another way, the objective of this paper is;

- To generate a guideline or method to find how automatically split activities under deferent constraints.
- To adapt quickly the changes of production scheduling from time to time.
- To deal with a multi-project and multi-size activities in each project.

Furthermore, the previous models have been assumed that all activities in FRCPSPs can be split. which is not true according to the activity categories that we have assumed and mentioned in this paper. From (Figure 5), the FRCPSPs in OKP system can be characterized as Flexible Resource Profile activities, Flexible project structure, multi-project schedule, and the activities are large-sized (e.g. daily orders are 2000-2500 in some windows and doors production companies which categorized as OKP companies).

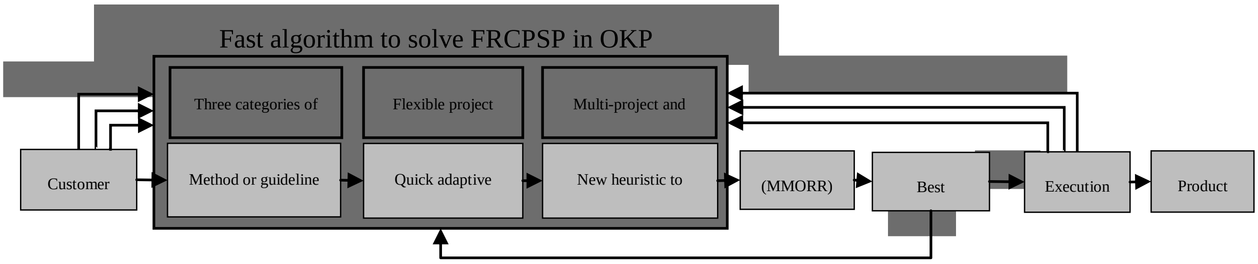

Figure 5. The new model proposed to solve FRCPSPs. in OKP.s

Managing OKP activities, as project production based, increases both the number of the feasible solutions for the problem and the efficiency usage of the resources and decreases the project duration. In the model proposed; we are going to attack the RCPSP, MRCPSP and FRCPSP in OKP as follows: if project activities included only the pre-determined activities i.e. category A&B, whether single or multi-mode, the model defines and deals with the problem as RCPSP or MRCPSP. In case the project activities included the non-predetermined activities i.e. Category C, in addition to other categories A&B, the model defines and deals with the problem as FRCPSPs, as depicted in (Figure 6).

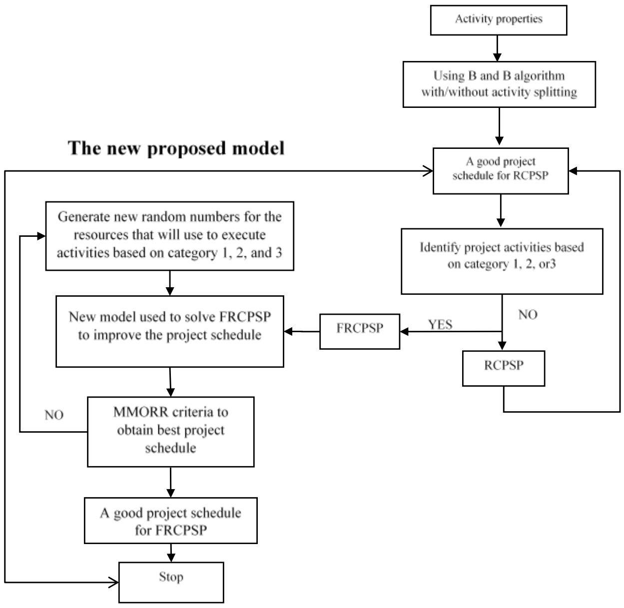

Figure 6. Flowchart for the new proposed model

According to the second case (the problem addressed in this paper): The work required to execute (FRP) activities has been referred as work-content ω, so the highest and the lowest quantity of resource required $\overline{R}$ and $\underline{R}$ should be identified in advance as a domain for resources required. Scheduler can identify the shortest duration $\underline{d}$ to execute the activity based on the highest quantity of resource required $\overline{R}$ as the first step. The Earliest start times (Es) and the shortest durations $\underline{d}$ for each project activity in category C is determined by dividing work-content on the highest quantity of resource required:

$$\underline{d} = \omega / \overline{R} \qquad (1)$$

The longest activity duration can be identifying when the resource required $R=1$, which means $\overline{d}=\omega$.

Next step is: using Gantt chart, ignoring the resource availability, and sorting project activities based on the relationships among them. After that, compare for each unit- time the resource required with the resource available and follow the next steps:

1. In case the summation of the resources required at any unit time less than the resource available, assign the resource available to complete these activities.
2. Assume at any unit-time, there is resource conflict is occurred between the activities in categories A, B, and C:
   a. Firstly, start by assigning the resource available on the activities in category A. Calculate the resources remaining by using

   $$R_r = R_{ava} - R_A \qquad (2)$$

   b. Secondly, assign the resource available R_r on activities in category B, and the rest can be assigned to cover a portion of the activity in category C.
   c. In case the summation of the resource required on activities in category A&B is more than the resource available, try to allocate the resource available on activities in category A&C, taking into the account the domain of the resource required allowed to complete the activity.

   $$R_C \neq R_{ava} - R_A \qquad (3)$$

It is worth mentioned in this paper that the model proposed consists of an algorithm that generates a huge number of execution modes based on the assumptions for the category C. For example, activity in category C has the work-content ω =3, and the highest and the lowest values of the resource required $\overline{R}=3$ *and* $\underline{R}=1$ respectively, and the activity could be executed during the period of 7 days because there are 4 days as slackdays. The number of the feasible solutions have been obtained equals 56 i.e. the activity can be executed by 56 ways as indicated below:

000003 000012 000021 000030 000102 000111 000120 000201 000210 000300 001002 001011 001020 001101 001110 001200 002001 002010 002100 003000 010002 010011 010020 010101 010110 010200 011001 011010 011100 012000 020001 020010 020100 021000 030000 100002 100011 100020 100101 100110 100200 101001 101010 101100 102000 110001 110010 110100 111000 120000 200001 200010 200100 201000 210000 300000

You can imagine the huge number of the project feasible solutions that could be created based on the number of project activities in category C, where each activity has different factors from others.

5. NUMERICAL EXAMPLE

To better understand the proposed model, let us consider the following example presented in 2003 [5], which will be used throughout this paper to illustrate the basic ideas and modeling frameworks.

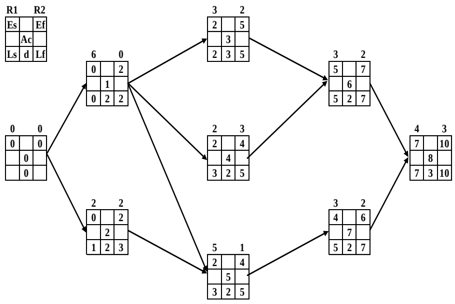

Figure 7a. The project network for the given example

The example of a project network is given to present project activities on the node (AON) as depicted in (Figure 7). The project is constrained by precedence relationships and resource constraints. From the perspective of the planners, the resources are usually allocated without considering competition for the resources of other activities. Therefore, the generated process plans are somewhat unrealistic and cannot be easily executed for a group of activities. Accordingly, the resulting optimal process plans often become non-feasible when they are carried out in practice at the later stage. In this example, the project completion time is 10 days, where resource requirements $R_1 \& R_2$ are 6 &15 respectively. Figure 8 shows the non-feasible project schedule because of violations exist in the resources.

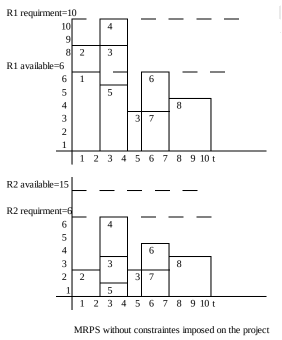

Figure 8. Non-feasible project schedule

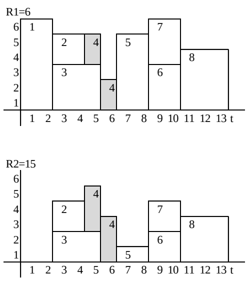

Figure 9a

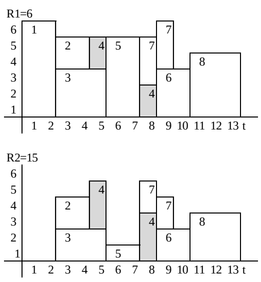

Figure 9b

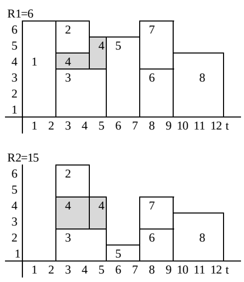

Figure 9c

When all project activities are classified as category A, i.e. project activities are non-preemptive with constant resource profile CRF, then the resource required to complete the activity 4 is 2 units from R1 and 3 units from R2 in 2 consecutive days as depicted in (9a), the project needs 13 days for completion. When some of project activities are classified as Category A (activities 1, 2, 3, 5, 6, 7, and 8) and some others as category B (activity 4) with constant resource profile CRP, then the resource required to complete activity 2 is 2 units from R1 and 2 units from R2 in 2 separately days as depicted in (9b), the project needs 13 days for completion. While, if the project activities are classified as Category A (1, 2, 6, 8), category B (3, 5, 7), and category C (4) with flexible resource profile FRP, then activity 2 needs 2 units from R1 and 2 units from R2 in 2 consecutive days, and activity 4 needs 1 units from R1 in the first 2 days and 2 units in the third day and needs 2units from R2 in 3 consecutive days as depicted in (9c), the project duration is reduced to 12 days. In worth mentioned, there is a high number of feasible solutions can be obtained by using the new model proposed to obtain the same results t=12 days as is in the third type; however, the best solution can be determined among them by applying the MMORR criterion.

6. CONCLUSIONS

As demonstrated in this paper, it is worth noting that using production schedules of PM.s in the OKP.s and classifying the activities into three categories, seems very affectively way to reduce the project duration, as well as project resource utilization in the OKP.s.

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