

## **RESOURCES SUAINABILITY PLANNING MODEL USING HIERARCHICAL APPROACH FOR CONSTRUCTION PROJECT**

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**ABSTRACT:** Within the early stages of construction project planning, resources restrictions are often neglected. Usually this leads to cost and schedule overruns. Moreover, the adoption of resources restricted project planning may lead to a complex optimization problem. Thus engineers should focus on resources-based project planning for more schedule efficiency. Nevertheless, the integration with traditional methods as the PERT (program evaluation and review technique) or the CPM (critical path method), can improve schedule reliability significantly in project failures due to insufficient resource allocation. Potential applications of resource-restricted project scheduling for construction project planning are revealed with some suggestions on the integration of this approach into traditional planning methods are made. For overlapping both, traditional planning methods as well as resource-based planning models, knowledge transferred from production planning to project planning by applying a hierarchical approach. Analyses of multi planning problems in construction projects are undertaken and the roles of the generalized resource-restricted project scheduling model and selected extensions within construction project planning are discussed.

**Keywords:** construction project, resource scheduling, planning, sustainability.

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### **INTRODUCTION**

The construction performance for any project, if it is considered as the obligation to delivery budget and dates as well as stakeholder satisfaction, is significantly affected by the quality of the project management. Mostly, common project planning techniques such as the Critical Path Method (CPM), the Metra Potential Method (MPM), as well as the Program Evaluation and Review Technique (PERT) concentrated on time oriented activities are used in practice. The advantages are the explicit representation of activity relations, interaction and

their easy application. Adversely, even though a lot of scheduling techniques were developed and tested for construction field, the scarceness of resources is often neglected in practice. Considering resources allocation especially that influence a project schedule as the project critical success factor, quantitative planning approaches, such as the resource restriction project scheduling problem (RRS), will improve and support the quality of project management. The resource and restricted problem does not only provide the opportunity to follow up the objectives like cost minimization or resource leveling but also considers resource limitations for project execution. Adopting the RRS to construction projects will raise optimization problems of high complexity due to the large number of variables. This not only impedes the acceptance of ideal planning approaches by practitioners, but also the applicability in a real construction projects. In response, a decomposition of the planning problem and use of a hierarchical approach for planning, considering both, traditional as well as sophisticated planning models, could improve the quality of construction project schedules.

Thereafter, a hierarchical approach for resource based construction project planning is presented. By this approach, the roles of quantitative resource-restricted project scheduling within the context of construction projects are investigated.

## **PROJECT PLANNING DESCRIPTION**

Construction industry projects can be described as a high complexity; this is the result of heterogeneous structure of buildings and infrastructures. They involve complex packages of work, for which design and contracting organizations are responsible; the product is generally large, discrete and prototypical. Moreover, external factors usually are not controllable (e. g. different stakeholder interests, availability of equipment and labor, supply of materials) influence project execution and lead to constantly changing project planning problems. More than any other industry, the construction industry is known for the often poor quality of its products and projects which are over budget and beyond time. Both, the late delivery as well as cost overruns in projects restrict project success leaving the client of the construction project unsatisfied and the contractor with expensive and time consuming dispute resolution and extensive claim management efforts. In the time that owners suffer of loss of revenue through, a lack of production facility, dependence on present facilities or a loss of income from rentable space, the contractor faces higher overhead costs due to, for example, longer

work periods, higher material costs caused by inflation as well as increases in labor costs (Assaf and Al-Hejji, 2006).

According to surveys among construction practitioners causes for delays are constant changes in project requirements, the development of multiple projects at the same time delaying less important projects, deficient communication between project partners, a lack of available resources, e.g. a shortage of site workers and technical personal, late delivery of construction materials, insufficient number of equipment and equipment allocation problems as well as a vague definition of the scope of project budget and schedules (Yates and Eskander, 2002; Yeo and Ning, 2002). As a conclusion, causes related to the planning and scheduling of projects are well known problems in many projects and significantly influence project success (Chan and Kumaraswamy, 1997).

### **PROJECT PLANNING APPROACHES: TRADITIONAL VERSUS RRS**

Since the late 1950s, CPM, MPM and PERT techniques have been focus of intensive research effort and wide spread use by practitioners in management to control a large scale construction projects (Galloway, 2006). Bearing the complexity of the construction project planning problem in mind, these project planning techniques cannot satisfy the specific needs of project planners in the construction industry (Herroelen and Leus, 2005). Simulation or planning approaches from Operations Research, such as resource restricted project scheduling with the well-known resource-restricted project scheduling problem (RRS) that integrates the scheduling as well as resource allocation process, represent an appropriate alternative to traditional planning methods. Comparing with traditional planning approaches, the development of the RRS is a more detailed schedule based on a larger set of information and, hence, a more realistic depiction of the construction project environment. The traditional as well as resource-based project scheduling approaches for the criteria ‘scope’, ‘basic principle’, ‘capacity planning’, ‘number of projects’, ‘objective’, ‘restrictions’, and ‘uncertainty’ are given in Table 1.

**Table 1** Brief comparison of the traditional and resource-restricted project planning approaches,

Thus, main objectives of construction project management and scheduling could be taken care of using the resources constrain. Moselhi and Lorterapong in 1993 refer to these objectives as the minimization of project durations under multiple resource restrictions, meanwhile, Tsai and Chiu in 1996 list that as the minimization of the total project delay, as

well as the minimization of costs of total resource consumption, including time and a leveled resource distribution. Moreover, objectives like maximizing the total project net present value by considering project delay penalties and early completion benefits (Chiu and Tsai, 2002) as well as finding the optimal resource selection optimizing time and cost objectives of a construction project are pursued. Furthermore, considering the repetitive activities, objectives might address the minimization of crew idle time. Finally, project management can address the generation of a schedule-dependent site layout planning.

### **ANALYSIS OF RESOURCE-RESTRICTED**

SWOT analysis or strength-weakness-opportunity-threats analysis of the RRS refers to the integrated time and capacity planning and the consideration of various resource types. This is especially important, as construction projects are characterized by a high consumption of a non harmonic collection of different activities. Moreover, it is applicable in construction for a wide variety of objectives, which include both direct and indirect stakeholders of a construction project. The possibility of extending resources restrictions allow for the consideration of externally given restrictions and the explicit representation of stochastic values for the duration and resource consumption of activities compensates the lack of experience on the exact distribution of these occurrences.

CPM, MPM and PERT leads to such planning without direct consideration of capacity restrictions. Even so, in addition to the fact that CPM, MPM and PERT are already proven in practice, they can compete with its easy to comprehend character, the less amount of information needed (activity durations, probabilities, resource consumption and availabilities for succeeding resource leveling), and, hence, it's easy computing, and implementation in current project management software. However, although the RRS apparently looks superior, it is of a more realistic description of the planning problem due to the more information has to be regarded as well. On the one hand models become more complex due to the risen number of restrictions and variables. Hence, although efficient heuristics in solving the problem had been developed high computing times still occur due to this complexity. On the other hand, the more information needed, the more information have to be collected which is either time consuming or not possible due to a lack of information and the unique nature of the projects. As a conclusion, both traditional as well as resource-restricted (i.e. RRS and extensions), project planning approaches are harmonized because of their appropriateness for various planning contexts.

## **HIERARCHICAL PLANNING**

To overcome the obstacles of resource-based project planning approaches there is an option for decomposition the planning problem and applying both, traditional as well as resource based approaches. Also, this supports the dynamic and uncertain environment in which project management is forced to forecast a number of situations during initial planning and subsequent refinement of the project plan. This requires a numerous decisions over a defined time horizon in increasing level of detail. In production management, decision processes of an organization can be related to three different planning levels: Strategic decisions, Tactical decisions, and Operational decisions.

Strategic decisions, such as policy formulation and capital investment decisions, meanwhile, Tactical decisions comprising aggregate all production planning activities, and the Operational decisions related to production scheduling

While the strategic decisions are made, tactical as well as operational decisions represent the actual production line or product. As production planning, project management includes planning activities which range from the tactical level to the operational level. Decisions are aggregate early at the tactical level in the planning process. This type of decisions has a longer time horizons, and usually cover the whole project make span. Tactical decisions comprise setting due dates and the procurement of material. In contrast, detailed decisions are made in operational planning and based on more accurate information. For instance, the scheduled resources allocation to project activities can be postponed just before the actual operation of a sub-project to benefit from minimized uncertainties in project progress, due to for instance, changing weather conditions or machine break downs causing project interruptions. Thereby, the scheduling of specific activities must be established in light of an appropriate trade-off between time, cost and resource usage. The time horizon of detailed decisions is necessarily shorter, usually contains the duration of one sub-project or work-package. Thereby, Figure 1 reflects the decomposition of a project into sub-projects, related activities and resource assignments.

For the integration of both, tactical as well as operational planning decisions, into the decision process hierarchical planning approaches are proposed for production planning. Hierarchical systems apply mathematical programming models for decision making at each level. Thus, the solution of a higher level model imposes restrictions on the lower level, while interaction and feedback cycle are allowed and ensure the integration of both levels. Reasons for the application of hierarchical planning models can be found in the reduction of

complexity by decomposing the planning problem into sub-problems and the possibility to deal with uncertainties. For instance, if detailed and aggregated decisions were made at the same time, much information for detailed decisions is not yet available and the decisions would have to be based on uncertain information and unreliable forecasts on future developments.

## **EXPERIMENTAL WORK**

According to the different decision levels when projects are addressed, project performance could be improved explicitly by considering both, tactical as well as operational decisions. This could be realized by a hierarchical approach for the planning process, similar to hierarchical planning approaches for production planning, making use of both traditional as well as resource restricted project planning. A hierarchical two-stage decomposition approach for project planning and scheduling is proposed and shown in Figure 2. In this approach, the methodology decomposes the project planning process in two stages, relative to the tactical and operational levels. The tactical planning level, “project level“, represent the project containing the long term planning and conducted with traditional project planning methods without the consideration of limited resources. The tactical level, “sub-project level“, focuses on the scheduling of sub-work of the project, so called sub-projects, considering scarce resources. Both decision levels are interacting by means of feedback loops. Especially, higher level decisions generates restrictions on lower level decisions while lower level decisions give feedback on updated schedule times to the higher level to ensure that the project schedule is in accordance to the resources availabilities.

At the first, the project goals and project structure have to be defined on a “project level” in terms of sub-projects, activities and related estimated durations and precedence relations. Thereafter, traditional methods like CPM, MPM or PERT can be used to generate a project schedule with the objective of minimizing the project overall duration. For the resulting schedule, milestones can be assigned to each sub-project. The milestones can be based on the schedule or consider a given project completion date. If milestones are based on the schedule minimizing the project duration, they take buffers and critical activities into consideration. As a result, the possibility of project schedule can be resource loaded can be exist with common yet not optimal techniques before the assignment of milestones. If milestones for sub-projects are based on a given project completion, sub-projects might be allowed to have a larger buffer and milestones can be adjusted accordingly.

The integration of time and capacity planning for the resources availabilities has been fairly neglected at the tactical level. Hence, the initial schedule has to be consecutively updated by planning the particular sub-projects in detail with an integrated time and capacity planning in the short term. So, detailed planning can be postponed directly before the actual execution of the sub-projects as more accurate information is allowed within project progress. This reactive planning technique ensures that sub-projects are scheduled based on latest and more accurate information related to resource availabilities, interruptions of preceding sub-projects or changes in project requirements.

For sub-projects, the necessary input data of the integrated time and capacity planning can be derived from the outcomes of the planning on the tactical level. This can done throughout the setting of due dates or updated information on delays in project progress and activity specifications for the sub-projects, i. e. precedence relations, detailed estimates of activity durations and resource consumption, as well as resource availability of material, equipment and labor over the planning horizon.

The sub-projects are chosen in timely order and scheduled considering resource restrictions. If many sub-projects are to be processed in parallel, approaches of multi project planning can be adopted. Based on the results, feedback is provided to the next (tactical) level. In particular, if the resulting sub-project schedule is feasible in terms of the project milestone schedule a positive feedback is given to the project schedule and the milestones are confirmed. If the sub-project schedule is milestone infeasible two options exist: Either the project schedule is right shifted or the succeeding sub-projects are postponed while updating the project milestone schedule or the subproject is scheduled again by taking into account that additional resource could be supplied at a certain cost to keep the milestone schedule. Additionally, the scheduled sub-project is deleted from the set of sub-projects and the next available sub-project is chosen for integrated time and capacity planning if operation of the sub-project is to start in the short-term. Hence, the result of this planning procedure is a resource loaded project schedule on rolling time horizons benefiting from the easy application of CPM, MPM and PERT and the larger scope of the RRS to consider resource limitations.

Regarding project and resource planning, the application of the proposed hierarchical planning approach offers two major benefits:

1. Support the tendering and procurement or planning for critical resources
2. Support the procurement or planning for non-critical resources

The schedules based; CPM, MPM and PERT can be applied in the first stages of project planning when incomplete information is known about project progress. These schedules support tendering activities through rough estimates on project duration. Moreover, critical resources with long lead times and/or high costs, comprising both non-consumable resources (such as machines and manpower) and consumable resources (e.g. construction material) can be allocated or ordered in advance to ensure availability on time. In contrast, a resource-based schedule on the tactical level eases procurement of less-critical resources with short lead times, high availability and low costs (Schultmann and Sunke, 2007). There is no need to store resources on site well in advance and can be delivered just before execution of the sub-project. This also ensures that site space is not congested if preceding sub-projects are delayed. For resource based project scheduling, the RRS, as already mentioned can be applied. The RRS not only integrates capacity planning but can be adapted to specific project particularities, for instance, multiple execution modes for activities and multiple objectives of different project stakeholders. Thus, especially in the short term, customized planning can increase customer satisfaction and schedule reliability.

## **RESOURCE-RESTRICTED SCHEDULING**

After the hierarchical project planning approach, the next step is to analyze the appropriateness of the RRS for the planning of construction projects. One should take a care of the huge amount of work existing on resource-restricted scheduling in the field of Operations Research. The next sections are intended to give a comprehensive overview on solution approaches for possible planning problems in dependency on the objectives and restrictions of construction projects for which the RRS could be applied.

## **GENERALIZED RRS MODEL**

In its basic formulation, the RRS describes a single project which consists of  $n = 1, N$  activities, also known as jobs, operations or tasks, with a known constant duration of  $d_n$  periods. It is characterized by a deterministic finish-to-start precedence relation in an Activity-On-Arrow (AOA) network, which considers that an activity cannot be started before all its predecessors have been finished. Furthermore, pre-emption of the jobs is not allowed, i.e. whenever a job has been started at the beginning of period  $t$  it must be performed without interruption in the time periods  $a, \dots, a + d_n - 1$ . Thus, each job  $n$  can be performed during its time window gained with backward and forward recursion from CPM scheduling, with  $EF_n$



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denoting the earliest and  $LF_n$  representing the latest finishing time of job  $n$ . Moreover, resource restrictions have to be observed during the procession of the jobs. These resource restrictions are differentiated according to the renewability of the resources. Renewable resources are resources which are only available in a limited amount per period, for instance machines or workers whereas the amount of available renewable resources might vary from period to period. If resources are non-renewable they are restricted over the whole planning or project duration, e.g. budgetary restrictions.

Thereafter, unsustainable or non-renewable resources represent cumulative resources which are consumed over time without being replenished. At the end, doubly-restriction resources are defined to be limited both per period and over the whole project planning, for example the budget which is "renewed" at the beginning of every month but is limited in its total amount for the project. Hence, doubly-restricted resources can be described as a combination of renewable and non-renewable resources and therefore do not need to be considered as separate resource type in further reflections. So, in the RRS job  $n$  requires constant  $q_{nr}$  units of the renewable resource type  $r \in R$  during every period of its duration. The resource type  $r$  is known and available in a constant amount  $Q_r$  over the project planning. Thus, jobs might not necessarily to be scheduled at their earliest possible (precedence feasible) start time. The objective of the RRS is to find a non-pre-emptive schedule (i.e. a feasible schedule) by assigning starting times to each jobs that the precedence and resource restrictions are satisfied following one or more targets. An early mathematical programming formulation was given in. With the assumptions made the RRS can be modeled as Mixed Integer Program (MIP) as introduced in the following:

The objective function (1) minimizes the project finishing time with  $\bar{A}$  being the end of the planning horizon.

$$\text{MIN } \bar{O} = \sum_{\alpha=EF_N}^{LF_N} \alpha \cdot x_{Na} \tag{1}$$

Restrictions (2) ensure that every job is processed once.

$$\sum_{\alpha=EF_N}^{LF_N} x_{Na} = 1 \quad n = 1, \dots, N \tag{2}$$

Restrictions (3) are precedence restrictions of jobs with  $P_j$  denoting the set of immediate predecessors of job  $n$ . The duration of job  $n$  is represented by  $d_n$ .

$$\sum_{\alpha=EF_h}^{LF_h} a \cdot x_{ha} \leq \sum_{\alpha=EF_N}^{LF_N} (a - d_N) \cdot x_{Na} \quad n = 2, \dots, N; h \in P_n \quad (3)$$

Restrictions (4) limit the resource demand  $q_{nr}$  of the renewable resource  $r \in R$  of jobs  $n$  which are currently processed in order not to exceed the constant resource availability per period  $Q_{ra}$ .

$$\sum_{N=1}^N \sum_{\tau=a}^{a+d_N-1} q_{Nr} \cdot x_{N\tau} \leq Q_r \quad r \in R; a = 1, \dots, \bar{A} \quad (4)$$

Finally, restrictions (5) define the decision variable  $x_{na} \in \{0,1\}$  as binary, with  $x_{na} = 1$  if job  $n$  ends in period  $a$ , 0 else.

$$x_{Na} \in \{0,1\} \quad N = 1, \dots, n; a = EF_N, \dots, LF_N \quad (5)$$

The RRS in its generalized form can be applied to several cases in project planning. However, in construction projects several particularities have to be considered if one aims at developing appropriate models for a good transformation of the real world project environment and planning conditions into the model. These conditions comprise:

- Alternative processing of construction activities
- Multiple simultaneous construction projects
- Construction project performance

## **CONSTRUCTION ACTIVITIES ALTERNATIVES**

It is very common in practice, to adopt alternative processing scenarios of construction activities and are many evident in the wastes of buildings deconstruction. Anyway, the deconstructed material quality and its suitability for recycling can be affected by the technical and organizational planning of the deconstruction process and, hence, the depth of the deconstruction process as well as the chosen processing option. These distinct processing options are modeled as modes  $m$  in resource-restricted project scheduling problems. These modes are representations of either resource/resource trade-offs or time/resource trade-offs (in contrast to time/cost trade-offs as addressed). Time/resource trade-offs occur when the duration of a job is affected by the bundle of input resources and can therefore be decreased/increased at the expense of providing additional/less resources or by using different resources. Resource/resource trade-offs are a special case of time/resource tradeoffs and represent the substitution of the resources needed to execute a job without affecting the duration of the job (considering that resources are substituted with resources the term resource/resource trade-off is not quite suitable, as there actually does not exist a trade-off between resources). Other examples might also include working overtime or replacing manpower with machines.

While in the RRS each job is processed in a single mode, i.e. each job is assigned a deterministic resource consumption and a corresponding time, the modeling of the RRS using modes results in the multi-mode resource-restricted project scheduling (MMRRS) problem. In this case, formulation each job  $j$  is assigned a mode  $m$  defining the relation between resource consumption  $q_{jmr}$  and job duration  $d_{jm}$  in one of several different modes  $m = 1, \dots, M_j$ . Additionally, “the implementation of a job may required resources types of renewable  $r$ ,  $r \in R$  as well as non-renewable  $n$ ,  $n \in N$ ”, while in the single-mode case (RRS) non-renewable, e.g. budget and material, are disregarded as either the amount of them is sufficient to process the project over the planning horizon or not. The primary objective is, according to the RRS, to minimize the project finishing time by selecting an execution mode for each activity and assigning feasible finishing times of the jobs according to the resource and precedence restrictions.

## **MULTIPLE PROJECTS MODE**

In the cases of resources shared among projects, difficult scheduling problems would arise if projects are to be scheduled in parallel. This situation very common for organizations

which must simultaneously manage a variety of projects subject to resource and due date restrictions, for instance, construction contractors, engineering firms, and maintenance crews. This comprises the assignment of scarce resources to different projects or shifting them from construction site to construction site, generally, minimizing time or cost objectives. The situation of parallel multiple projects planning, multiple projects have to be introduced in the model. Extending the MMRRS, a multi project scheduling problem consists of a number of independent projects given by  $i = 1, \dots, I$  which simultaneously compete for limited resources within their project specific precedence relations of finish-to-start type whereas resource transfer times between the projects are assumed to be negligible.

In contrast to the objective of the RRS and MMRRS, which is commonly minimize the project finishing time as only one project is scheduled; a relative measure has to cope with multiple projects, i.e. a mean value of an objective. Considering that projects usually come in late the objective of the basic model for the multi mode multi project scheduling problem under restricted resources with the multi-project approach is to minimize the mean project delay *MPD*, whereas the project delay is the difference between the resource-restricted project finish and the due date of project  $i$ .

Construction project performance can be defined as the adherence to time, cost and quality objectives, and recently also acknowledging additional objectives like the sustainability and environmental performance of construction.

## **DURATION OF CONSTRUCTION PROJECT**

It is common, in construction projects to find many sub-contractors and suppliers that selected and have to be scheduled for a particular project by a particular instance. The involvement of these parties in a project depend on each other and may cause delay for each other. In the RRS, this situation can be modeled by considering each single activity and its delay within the schedule by minimizing the delays of activities. Thus, it can also be recognize whether a given due date exists and serve as basis for the calculation of limiting time interval in which each activity can be executed. If, in case multiple projects are to be considered as typical for construction contractors, this project is scheduled minimizing the mean multi project delay over all projects, unlike a single project in CPM and PERT. Time-based objectives in projects point the optimization of measures related to finishing times, tardiness of activities and projects. With the RRS, for instance, the following objectives could be considered (Kolisch and Padmann, 2001):

- Minimization of the make span of a project  $i$ ,
- Minimization of the (weighted) flow time of activities  $j$ ,
- Minimization of the (weighted) delays of activities for given activity due dates  $dd_j$ ,
- Minimization of the mean multi project delay for given project due dates  $dd_i$  under simultaneous consideration of more than a single project.

## **CONSTRUCTION PROJECT PROFIT**

Different contractual instructions, in construction projects, define the financial conditions of the project, as fixed price contracts, lump sum, and others. The payments of the client shall cover the costs of the construction contractor or sub-contractor for the execution of its work package. Thus, costs can be considered as expenses triggered by initiating activities for instance for resource consumption, for additional resource costs  $c_r$  for renewable as well as  $c_n$  for non-renewable resources if a project deadline has to be met, such as the construction contractor acquires additional equipment or labor to avoid the imposed contractual penalty by the client. Moreover, costs can occur for set up activities but also for incurred project delay penalties  $p_i$  and other payments to be made during construction project progress. On the other hand cost or related cash flows can be contractual or not-contractual agreed progress payments by the client for the completion of parts of the project or final completion. Hence, monetary oriented project objectives comprise resource-cost oriented objectives, activity-cost oriented objectives as well as objectives concerning the cash flow or net present value of a project (Kolisch and Padmann, 2001).

Generally, *resource-cost oriented objectives* are reflected in two extensions of the RRS: time-restricted project scheduling problem (TRPSP) and resource investment problem (RIP). The objective of the TRPSP is the minimization of additional resource costs for additional resource consumption if the project finish is set. The RIP aims at determining a non-delay schedule and the amount of each resource provided minimizing total costs. Considering activity-cost oriented objectives also known as time/cost trade-off problems occur. The underlying assumption is that the activity duration might be influenced by the amount of money spent for processing. Research discussing the time/cost trade-off problem can for instance be found in (Vanhoucke, 2005). Moreover, penalty costs for project finish negative as well as positive *cash flows* as reflected in the NPV of a project can be considered, as for instance agreed upon in a Guaranteed Maximum Price (GMP) contract with a bonus clause in construction. Problems aiming at maximizing the NPV are called resource-restricted project

scheduling problem with discounted cash flows (RRS-DCF), e.g. (Chiu and Tsai, 2002) with various extensions, for instance, for multiple-projects, for multiple processing modes or varying payment models, e.g. (Kim and Leachman, 2003; Mika et al., 2005).

## **SUSTAINABILITY OF RESOURCE UTILIZATION**

In construction projects, usually a large number of equipment needed, such as cranes, scaffolding which is cost-intensive. Therefore; utilization of these equipment and facilities result in some unnecessary costs. Hence, resource utilization should be managed at multi-leveled. This case is considered as resource multi-leveling problem, While their costs are the essential part, the focus of resource oriented objectives is to allocate resources in such a way insure the minimization the deviations in resource consumption per period, rather than to allocate resources to activities maximizing benefits or minimizing costs.

Due to the high amount of construction wastes and deconstruction processes, sustainability of resources in construction extremely important. The consumption of energy in construction projects is another reason for high importance of sustainability. National and international regulations imposed in construction comprise for instance specific laws about energy consumption, waste management and on site control. The objectives of sustainability can present the maximization of material to be recovered in deconstruction projects or minimization of material required for construction. An extension of the RRS considering efficient deconstruction and recovery planning and the choice of appropriate deconstruction techniques been proposed. through this extension, the savings is additionally assigned to each process. Thus, integrates the saving by recovering the deconstructed material in comparison to using primary raw materials.

## **CONCLUSIONS**

In this proposed model of resources planning; the objective of tactical planning is time oriented by focusing on the early finish timetable. In contrast, the RRS is more suitable for a project having detailed planning and the sub-projects considering various characteristics and multi-objectives depending on the scope of the project. The combination of traditional and RRS project planning approaches might raise the acceptance of more sophisticated planning methods by practitioners and support the easy application to solve multi-variables. The RRS can be applied successfully to a variety of different elements of construction projects. It serves as a framework for resource management in construction project planning, at the same

time, it can also be adopted to different project structures and environments. Integrated with traditional approaches like CPM and PERT for detailed planning of construction project. This integration of resource planning, ensure that the RRS will improve the reliability of the resources schedule.

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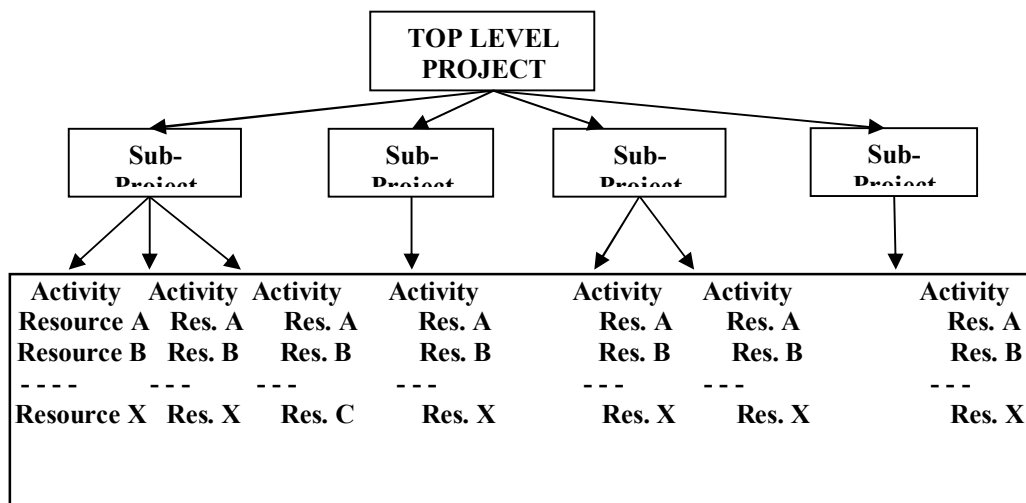
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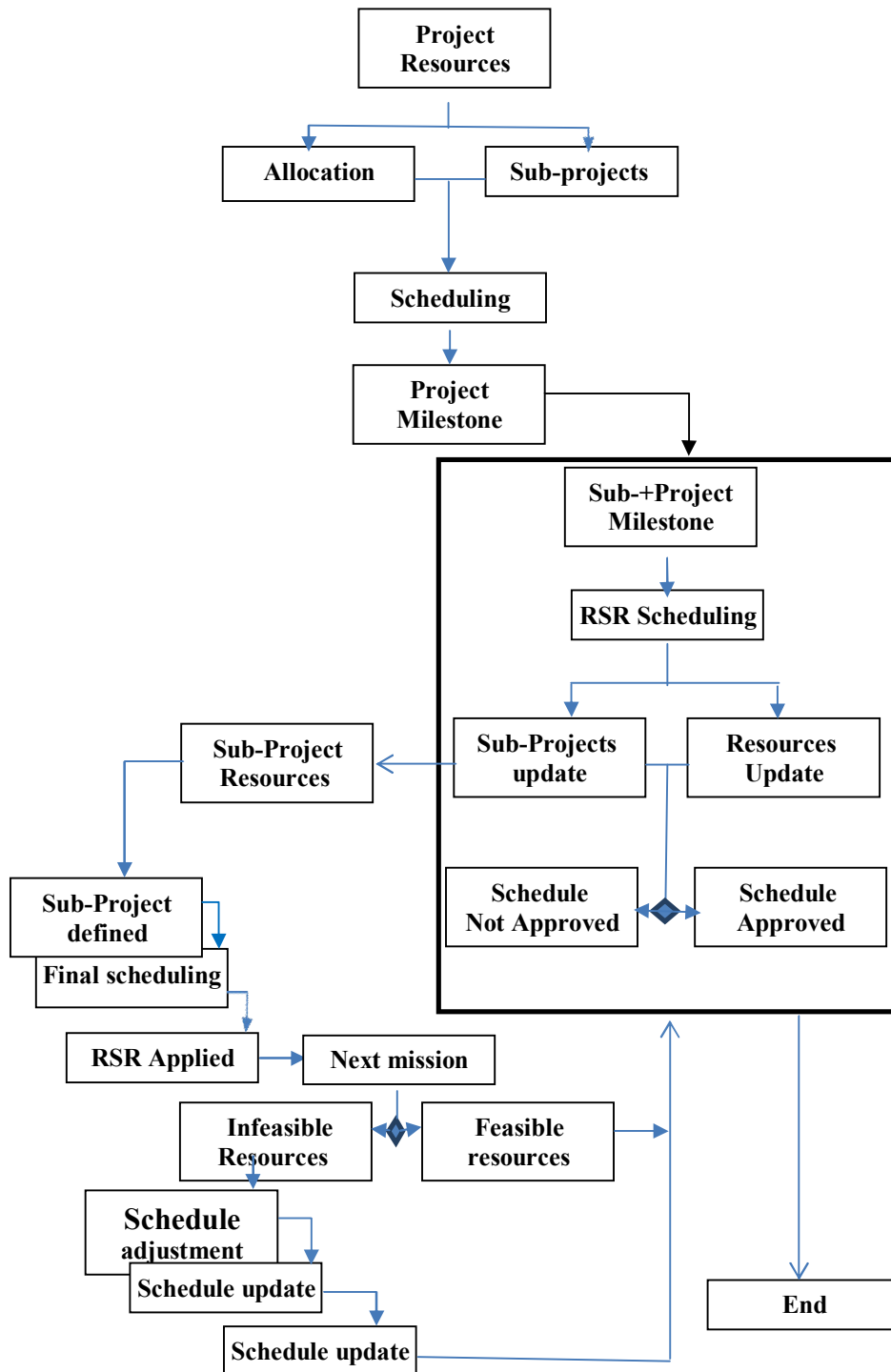
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**Table(1):** Brief comparison of the traditional and resource-restricted project planning approaches

Scope	Traditional planning approaches (CPM, MPM, PERT)	Resource-restricted project planning (RRS and extensions)
<i>Basic principle</i>	Time based	Resource based
<i>Capacity planning</i>	Sequential (succeeding resource leveling)	Integrated
<i>Number of projects</i>	Single	Single: Resource-restricted project scheduling problem (RRS) Multiple: Resource-restricted multi project scheduling problem (RCMPSP)
<i>Objective Type</i>	One type Time: Min project duration	Various types Time: e.g. MIN project duration, MIN project delay, MIN mean activity delays Money: e.g. MAX cash flow, MIN additional resource costs Resources: e.g. MAX resource leveling Environment: e.g. MAX energy savings
<i>Number</i>	Single	Single, multiple
<i>Restrictions Precedence restrictions</i>	One type Finish to start	Various types e.g. Finish-to-start, start-to-start, min-max time lags
<i>Processing modes</i>	Single	Single (RRS) Multiple: Multi mode resource-restricted project scheduling problem (MMRRS) with time-resource, resource-resource and time-cost trade-offs
<i>Resource types</i>	No consideration of resources during initial schedule generation	Non-renewable (e.g. budget) Renewable (e.g. equipment, labor)
<i>Uncertainty Activity durations Resource availability</i>	Probabilities: PERT	Applies to activities and resources Probabilities: Stochastic resource-restricted scheduling Possibilities: Fuzzy Scheduling



**Fig.(1):** Decomposition of a project.



**Fig.(2):** Hierarchical project planning approach.

## نموذج تخطيط الموارد المستدام باستخدام المدخل الهرمي للمشاريع الانشائية

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### الخلاصة

في مراحل التخطيط الاولى للمشروع الانشائي غالبا ما تهمل محددات الموارد. ان تبني تخطيط المشروع المتضمن محددات الموارد قد يقود الى مشاكل معقدة. وعليه يكون على المهندسين ان يركزوا على تخطيط المشروع باعتماد محددات الموارد لزيادة فعالية البرامج الزمنية. ان التكامل بين تخطيط المشروع ونظرية المسار الحرج او نظرية اعادة التقييم من الممكن ان تساهم في تطوير واقعية الجدول الزمني للمشروع وخصوصا في المشاريع المعرضة للفشل بسبب توزيع الموارد.

ان الاعتماد الضمني على اسلوب الموارد المحددة للمشاريع الانشائية تم تضمينه مع بعض المقترحات للتكامل مع انظمة الادارة التقليدية. ويتداخل الاسلوبين تم نقل المعرفة من التخطيط الانتاجي للقطاع الصناعي الى تخطيط المشاريع الانشائية باعتماد النظرية الهرمية. وبهذا الاسلوب يمكن تحليل اغلب الحالات لمشاكل التخطيط الانشائي وجعل النموذج المستحدث بصيغة عامة قابلة للتكيف مع خصوصية المشروع.

**الكلمات الاساسية:** المشاريع الانشائية، برمجة الموارد، التخطيط، الاستدامة