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# Project selection and scheduling for phase-able projects with interdependencies among phases

Ali Shafahi[a,*], Ali Haghani[b]

[a] Department of Computer Science, A.V. Williams Building, University of Maryland, College Park, MD 20742, United States
[b] Department of Civil and Environmental Engineering, 1173 Glenn L. Martin Hall, University of Maryland, College Park, MD 20742, United States

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## ABSTRACT

This research proposes a model for project selection and scheduling when some of the projects in the available pool of projects can be implemented in phases. We present a mixed integer programming (MIP) model that maximizes the Net Present Value (NPV) of future investments in situations where temporal budget limitations and reinvestment strategies exist. The MIP reveals the optimal phasing solution. It models the Interdependencies among different phases of a project and also takes the foundation/infrastructure requirements for development of future phases into consideration. To solve large-size problems, we present a solution method that initially reduces the problem size. Then, a two-step heuristic is presented that in the first step adds projects to the pool of selected projects one by one based on a favorability measure and in the second step, eliminates some phases of the chosen projects with some probability. The performance of the heuristic is illustrated through five small-size and four large-size examples. We perform sensitivity analysis by altering various parameters that affect the heuristic's performance such as different favorability measures, and different initial available budgets. The results are favorable for the preprocessing step and solution heuristic. On small-size scenarios, the heuristic can find the optimal solution from the MIP in almost all cases. Furthermore, on large-size scenarios, the heuristic finds solutions within approximately 100 s that are better than the ones found by solving the MIP given a 10,000 s time limit.

## 1. Introduction

One of the significant problems for management in the presence of many projects and budget limitations is the selection problem. If the projects under consideration are real projects such as construction projects, scheduling their implementation also becomes essential. In the presence of more funds, decision-makers can more easily disaggregate the pool of projects into separate individual projects that could be treated individually. However, in the more realistic case and a temporal setting, under limited funds, smart investment in a project greatly affects the availability of funds for future projects. Once funds are invested in a project, the available budget is decreased by the amount of investment. However, the budget will begin to increase upon arrival of revenues resulting from the investments. Some attributes that can make a project favorable are profitability and revenue collecting period. The sooner we start receiving revenue, the better the project is due to time value of money. The available funds increase by depositing the income received. In some circumstances, we do not need to wait until the entire project is completed to start receiving revenue. One example of such as situation is phased investments of projects.

Phasing a project is the process of dividing a large project into smaller pieces called phases. This process could increase the likelihood of at least some parts of the project to be economically feasible. This feasibility could be due to a decrease in the initial fund requirements for smaller phases. Also, the implementation of preceding phases can generate revenue and build the capital needed for future succeeding phases. In many cases such as construction projects, the implementation of future phases requires infrastructures/foundations that should be acquired before the implementation of the first phase. Consider the construction of a residential complex that has three buildings. One way to break the project is to consider each building as a separate phase. To build all three phases, we need to have acquired the land before implementation of the first phase. Another way to break the construction project down into smaller phases is to break it by each level. Zhao and Tseng [1] present a case study of breaking the construction of a parking lot into smaller phases. The foundation requirements would differ based on the number of phases that would be executed in the future.

Breaking projects into smaller phases also has its downsides. The ones considered in this research are losses in the economy of scale and the increase in construction duration. The economy of scales and

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[*] Corresponding author.
*E-mail addresses:* ashafahi@umd.edu (A. Shafahi), haghani@umd.edu (A. Haghani).

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scheduling relationships are examples of potential interdependencies among phases of the same project. Some projects also exist that either cannot be broken into smaller phases or breaking them into smaller phases is not economically feasible. The construction and rent of a single-story townhouse is an example as any decomposed phase of this little project does not generate any revenue and the revenue (due to rent) could only be collected once the entire project is completed. Realistic pools of projects are a mixture of multi-phase projects and traditional single-phase projects.

Scheduling of selected projects is another important decision in temporal settings which the projects' availabilities are within certain time periods. In such contexts, choosing the optimal time that a project should be implemented is important as it directly affects the feasibility and profitability of the project.

The project selection and scheduling problems have been widely studied individually. The simplest setting of the project selection problem is an example of the well-known knapsack problem. In the realm of project selection, a majority of the problems assume minimum or zero interactions. However, projects that fall into similar categories affect each other and have interactions. Some of the different interdependencies among projects mainly fall into benefit-cost, and outcome categories [2]. Due to the complexity imposed by adding interdependencies to project selection, finding a solution technique that is capable of providing good solutions is important. Different solution methods have been used in the literature such as goal programming [3], linear programming [4], branch and bound [5], heuristics [6], and Constraint Programming [7].

The project selection problem becomes further practical and at the same time more complicated when it is combined with other basic problems such as markup estimation [8]; or when its objective function is modified, and it is modeled as a multi-objective optimization problem. In the latter case, where we have multiple objectives, the problem is usually rebranded as “portfolio optimization.” For a relatively recent survey on portfolio optimization see Mansini et al. [9] and Carazo [37]. Project scheduling is one of the most important problems that is mixed with project selection. Scheduling is the process of finding “appropriate” times for execution of projects or activities. For a survey on deterministic project scheduling, we refer the interested reader to Kolisch and Padman [10].

If scheduling of a single project is affected by resource availabilities, the scheduling problem is branded as a “Resource-constrained Project Scheduling Problem” (RCPSP). RCPSP is an NP-hard problem, and many studies have focused on developing heuristics and solution algorithms. Chen et al. [11] use ant-colony to solve the RCPSP. Chan et al. [12] model a construction scheduling project as an RCPSP and use genetic algorithms to solve it. Gonçalves et al. [13] also, use GA to address the problem of RCPSP when we have more than one project. Kim and Ellis [14] use GA with elitism to solve the problem of scheduling for single projects. Brucker et al. [15] and Dorndorf et al. [38] solve the RCPSP problem using a branch and bound procedure. Demeulemeester & Herroelen [16] describe a branch and bound procedure that is used for solving the RCPSP for a single project. They later update their procedure and test the updated version on different problems [17]. Zhang et al. [18] use Particle Swarm Optimization (PSO) for solving RCPSP with the objective of minimizing the duration and compare the performance of PSO with GA. Hartmann & Kolisch [19] and Kolisch & Hartmann [20] compare some of the different heuristics used for solving the resource constraint scheduling problem. RCPSP has many variations, some of which can be found in [21]. Another famous scheduling problem studied, especially in computer science is job shop scheduling. The focus of this problem is scheduling the jobs and assigning them to the machines that can execute them. Job Shop Scheduling problems assume all jobs have to be performed. In other words, there is no selection of the jobs.

The integration of project scheduling and project selection is essential since once we have selected a project, we should also determine its schedule. In contrast to the amount of research available for project selection, and project scheduling independently, very few research focuses on the intersection of these two problems [6,22]. Chen & Askin [23] present a MIP formulation that models the joint selection and task scheduling problem. Their objective function is maximizing the Net Present Value (NPV) of profit. Shariatmadari et al. [24] also, present a MIP for solving the simultaneous selection and scheduling model in the presence of renewable and non-renewable resources.

In the area of the integration of project scheduling and selection, even fewer studies exist that in addition to modeling these two problems simultaneously, consider some interdependencies as well.

Tao and Schonfeld [25,26] consider the problem of scheduling and selection of interdependent transportation projects. They capture interdependencies beyond more than just pairwise dependency between projects and develop an island model for solving the problem. Island models are variants of the traditional GA models that generally achieve better results in comparison to traditional GAs. In another study by Shayanfar [27], the authors try to prioritize the projects and compare three different metaheuristics, namely GA, SA, and TS. They conclude that for their application of scheduling and selection with interdependencies, GA yields the most consistent solutions.

In Zuluaga et al. [28] a MIP formulation for the selection and scheduling problem is presented that includes resource, technical, and benefit interdependencies between projects. The authors also include scheduling relationships. In Ballou and Tayi [29] a framework for facilitating software maintenance projects and their staffing is provided. Initially, the selection process is modeled as a MIP, and afterward, for the selected projects, staffs are assigned based on a transportation algorithm. Dash et al. [30] is another example that presents a MIP for the joint scheduling and selection problem in the presence of resource constraints and interdependencies. Tofighian & Naderi [31] use ant-colony to solve the integrated selection and scheduling problem. They consider two objectives: maximizing benefit and minimizing the maximum level of required resources. The only type of interdependency they model is mutual exclusiveness. Their study lacks re-investment strategies.

The study by Jafarzadeh et al. [32] has re-investment strategies such that the profit yielded from completing projects can be invested for implementing other projects. The planning horizon in their study is flexible, and one objective of their study is to find the best time horizon. Although they consider re-investments they do not model interdependencies among projects and assume that each project is independent. They model the problem as a MIP and show that their problem can be tackled by commercial solvers. Another study that allows for reinvestment is Belenky [33]. In one of the generalized cases in the study, scheduling interdependencies and priorities are considered. Carazo, et al. [6] allow transfer of unused funds between the current and the next time period within their modeling. They consider existing synergies among projects when they are done at the same time. Their MIP model is nonlinear, and hence they solve the model using a two-step method. The first step is Tabu search and the second step is scatter search. Wang & Song [34] and Medaglia et al. [35] develop MIP models that maximize the NPV. The model is applied to a case constructed surrounding a study of a Latin American sewage and water company.

Very limited studies perform portfolio optimization on a set of “divisible projects” [36]. They do not consider the infrastructural requirements for future expansions. To the best of the authors' knowledge, no study exists that models the integrated project selection and scheduling problem for a pool of projects that themselves can be broken down into sequential phases that require infrastructure investments. This study aims to fill this gap by expanding single project deterministic phased investment problems into models that can handle the optimization of a pool of phased projects. Specifically, the objective of the model presented in this research is to assist program managers in selecting which projects to implement and their respective schedule. The overall goal of this research is to help managers making simultaneous