Factors Influencing Project Duration in Multi-Project Environments: A Study in a Public Works Engineering Division

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Estimation of the project duration in the planning stage plays an important role in engineering and construction industries. These environments often operate in multi-project settings thus the estimation of project duration is often complex and unexplored. In this research, we analyze the project durations in a public works engineering division which operates in multi-project settings. We have conducted this exploratory study using actual resource usage data over eleven years and identified the factors that impact projects durations. We postulate observations and discuss their implications on future research and on practice.

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I. INTRODUCTION

Importance of estimating project duration in engineering and construction environment during the planning based on the information available is evident from research articles published recently. For example, Irfan, Khurshid, Anastasopoulos, Labi, and Moavenzadeh (2008) investigate the estimation of highway project duration on the basis of variables known at the planning phase such as planned cost, project type and contract type. They indicate that good estimate of the project duration is useful in bid evaluation and in cases where bidders are asked to specify construction periods. This research estimated the project duration using the actual durations and costs of past construction projects. Hussain and Ruwanpura (2010) developed an optimization model that establishes the relationship between project duration and resource requirements. In this study project duration refers to the time required to complete the construction work of a project and “resource” means the manpower deployed by the general contractor. They show that if duration of a project decreases then resource required normally increases and vice versa. However, the rate of change of increase or decrease will not be the same for all types and sizes of projects. A number of similar nature and type of projects were investigated to derive a suitable relationship between time and manpower requirement using data collected from three leading construction companies.

As discussed above, prior research in engineering and construction have presented approaches where the project duration is estimated using the attributes of individual projects such as resource requirements and project types in single project environments. However, it has been reported that 90% of all projects, by value, are carried out in multi-project environments (Hussain and Ruwanpura, 2010; Payne, 1995). Generally, these projects are smaller than their large unitary contemporaries. They do not, therefore, have the luxury of dedicated resources and they must share at least some resources with other projects. As soon as the need for a new project is realized, it is routed to the appropriate resource(s) where it joins a queue of other projects that entered the system at earlier times. It is quite common to find that these projects are competing for the resources. Further, concurrent projects are often intertwined due to internal and external dependencies.

From a project management perspective, the multi-project environments are more challenging and pose several unique problems and issues. The estimation of project duration is likely to be impacted by those problems and issues. We made the following two observations based our literature review: (1) estimation of project duration in multiple project environments is an unexplored topic, and (2) the project duration estimation approaches in engineering and construction do not incorporate the characteristics of multi-project settings. This research aims to connect these two research streams. Specifically, the objective of this research is to explore the factors that drive the project durations in multi-project engineering and construction environments. We conduct this research in engineering division of a public works agency that operates in multi-project setting. We collected resource usage data by projects over eleven years, analyze the patterns in resource loading during the life of the projects, and identified factors that impact project duration using regression models. We have summarized key findings as observations, which can spur further research and also discussed the managerial implications.

The remaining part of the paper organized as follows. In Section II of the paper we analyze the literature and state the research objectives. In Section III, we describe the research context and research model. Then, in Section IV we describe the data collection and present the empirical results. Finally, in Section V we make conclusions and provide some perspectives on further research in this area.

II. LITERATURE REVIEW AND RESEARCH OBJECTIVES

As described in the introduction, estimation of project duration is important at the planning stage. A number of articles have presented approaches to estimate project durations in the context of single project environment and employed attributes of individual project. For example, Hussain and Ruwanpura (2010) model the project duration based on the resource requirements. They show that if duration of a project decreases then resources required normally increase and vice versa. In fact in traditional project management literature, the project time and cost are derived by estimating detailed resource requirements for the activities involved. Irfan, Khurshid, Anastasopoulos, Labi, and Moavenzadeh (2008) present a model where highway project duration is estimated using the variables such as planned cost, project type and contract type. The idea here is that the project duration is likely to correlate strongly with the project cost and project type.

As discussed in the introduction, a large percentage of engineering and construction projects are done in multi-project environments where the assumption of traditional single project environment is far from reality. The project duration is likely to be impacted by complexities and issues associated with the multi-project environments. The multi-project management literature talks about a number of such complexities and issues, but estimation of project duration is not examined. We want to review the articles published in the multi-project management area and identify the factors that can impact project durations.

Two prime organizational features of a multi-project environment are: (1) the presence of more than one active project and (2) a shared pool of resources from which all projects must draw from. The goals in understanding multi-project environment is formulating an effective planning and scheduling to deliver projects in a minimum amount of time while maximizing the utilization of resources. In many cases, the latter goal is often considered secondary due to a general tendency to over commit the available resources to too many projects. Payne (1995) observes: "In just about all cases, a portfolio of projects will always be under-resourced as a cost saving measure. Hence, the resource constraints create interdependencies even if the projects in the portfolio are independent (Dobson, 1999; Pennypacker and Lowel, 2002). Laslo and Goldberg (2008) state that in multi-project environment the vast majority of the projects compete against each other for the allocation of scarce resources. If a number of projects are started concurrently, the resource capacities necessary to guarantee the achievement of one project's objectives may impede allocations to other projects and reduce the overall successes of the organization. As a consequence, there may be particularly intense internal lobbying activities for available resources. Furthermore, attempts to optimize resource allocations are complicated by differences in project activities, due dates, and the nature of penalties for projects that fail to meet their objectives.

Resource allocation and project scheduling is an extensively studied topic in the multiple project management area. For example, Browning and Yassine (2010) indicate that managers of multiple projects with overly constrained resources face difficult decisions in allocating resources to minimize the average delay per project or the time to complete the whole set of projects. Their research addresses the static resource-constrained multi-project scheduling problem (RCMPSP) with two lateness objectives, project lateness and portfolio lateness. Lova, Maroto and Tormos (2000) present a multi-criteria heuristic algorithm for multi-project scheduling, which has two phases. The first phase obtains a good schedule for the multi-project by minimizing the mean project delay or minimizing the increase in multi-project duration (both criteria are time based). The second phase improves the schedule generated by the first phase with non-time criterion: project splitting, in-process inventory, resource leveling or idle resources. Anavi-Isakow and Golany (2003) propose a new project control mechanisms that limits the number of active projects in multi-project environments, which is based on the concept of constant work-in-process (CONWIP) that was proposed earlier in the context of production management. Hence, the number of concurrent (simultaneous) projects that are competing for the resource pool is an important variable that impact project durations.

One frequently made assumption in both single project and multi-project environments is constant resource loading. The typical project management problem will assume that once a resource is allocated to a task (or project); the effort applied will remain steady and unwavering until the completion of said task (or project). Another assumption is that no resources will be added or removed from the task once it has commenced. A third assumption is that resources are fully committed to a task until completed and is prevented from working on other tasks simultaneously. These assumptions are overly simplistic and far from reality. For example, Browning and Yassine (2010) acknowledges the existence of variable resource loading that occurs in projects. His paper analyzes various resource loadings distributions including front-loaded, not-front-or-back-loaded, and back-loaded. There are several reasons for variable resource distributions to occur.

Yang and Sum (1997) examine the performance of due date, resource allocation, project release, and activity scheduling rules in a multi-project environment where significant resource transfer times are incurred for moving resources from one project to another. When a project arrives, its due date can be assigned by the customer, the higher level manager, or both. In most cases, both the higher level manager and customer are involved in setting a project due date. Since the higher level manager has more information on the system workload and resources available, he usually proposes the initial project due date. The higher level manager and customer will then negotiate and agree on the final project due date. Once the due dates are agreed, the higher level manager allocates resources to the projects. Since most resource allocation rules rely on project due dates, potential interaction exists between the due date and resource allocation rules, which authors refer to as due date nervousness. This, in turn, causes resources to spread over too many projects; and many activities are delayed while waiting for the right combination of resources. They argue that a good project release rule can, therefore, improve the performance of due date sensitive resource allocation rules by limiting the number of active projects competing for resources and by preventing resources from alternating among too many active projects.

Payne (1995) identifies issues associated with multi-project management and classifies the issues into the following categories: capacity, complexity, conflict, commitment, and context. Capacity relates to the ability of the organization carrying out the multi-projects to provide sufficient and appropriate resources. The author states that balance between resource requirements and resource availability, is rarely achieved. The dimensions of conflict considered in the review are: people issues, systems issues, and organizational issues. Commitment relates to the commitment to individual projects of the parties working on, or providing resources to the projects. Context relates to the setting of projects, such as the culture, procedures, and norms of behavior of groups or societies. Three areas of complexities are identified which are the simultaneous management of multiple projects that differ in terms of size, required skills, and urgency. Complexity relates to those aspects concerned with the multiple interfaces between the projects, the projects and the organization and the parties concerned. A multi-project has, in addition to its internal interfaces, interfaces with external environments. These may not be direct, but via intermediaries such as common-resource providers. The interaction of interfaces between the multiple projects can lead to technical compromises.

Engwall and Jerbrant (2003) indicate that past research has treated the resource allocation syndrome primarily as a planning and scheduling issue, and states that this explanation is too simplistic. Their research which is based on two case studies indicates that the primary management issues revolved around resources. The portfolio management was overwhelmed with issues concerning prioritization of projects and, distribution of personnel from one project to another, and the search for slack resources. The allocation of resources to (and between) simultaneous and successive projects is a process of politics, horse trading, interpretation, and sense making that is far more complex than what is traditionally described. They characterize the mechanisms that influence the resource demand and resource supply. Hansa, Herroelenb, Leusb and Wullinka (2007) survey several viewpoints on the complexity of multi-project planning under uncertainty. They indicate that the multi-project organizations are characterized by a high degree of complexity (interdependencies) and uncertainty about the activities and operations. They provide an integrated approach to multi-project planning under uncertainty that deals with both the complexity aspects of the problem and with the uncertainty. This framework is based on the dimensions variability and complexities of an organization. Further, they propose a hierarchical framework for project planning and control, which distinguishes four hierarchical levels: rough-cut capacity planning (RCCP) at tactical level and resource-constrained project scheduling (RCPSP) at operational planning level. De Meyer, Loch, and Tisch (2002) categorize uncertainties into four types: variation, foreseen uncertainty, unforeseen uncertainty and Chaos. Further, he states that each type of uncertainty requires a different set of managerial strategies and tactics in order to effectively complete a project.

External dependencies are a measure of the extent a project is influenced by outside factors. Herroelen (2005) classified projects along dimensions "dependencies and variability" and defines four class types of dependencies and variability. He argues that different management approaches should be applied to each of the different category of projects. Payne (1995) touches briefly upon the ideas of trade-offs and urgency versus importance. Multi-project environments will inevitably advance the interests of select projects against the interests of the remaining projects in a portfolio.

Our literature review suggests that the estimation of the project duration is typically done in the context of single project environment using variables such as resource requirements and project type. As discussed above, the multi-project environments pose unique challenges and issues. Hence, the project duration is likely to be impacted by factors such as: number of concurrent projects, project priorities, internal/external interdependencies, due dates and organizational issues. The objective of this research is to explore how these factors pertaining to individual projects as well as the multi-project setting, influence the project durations. We conduct this exploratory study in a real life setting, which is explained next.

III. RESEARCH CONTEXT AND THE CONCEPTUAL MODEL

The study will be based on data acquired from the engineering division of a public works agency. The study will examined the activities of a design engineering group consisting of an average of six engineers involved in roadway projects within a Capital Improvement Program (CIP). The CIP is a master planning entity that briefly describes the scope and authorizes funding for each project. These projects are then assigned to various organizations including the public works agency for construction. The design group (hereinafter "core project team") is one of several divisions within the public works agency whose job is to design and manage roadway projects to a point where it is ready to be handed over to the construction divisions as shown in Figure 1.

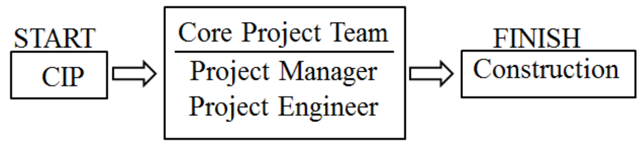

FIGURE 1. The Research Context

The core project team consists of project managers and project engineers. Most projects have one of each. However, larger projects may have one project manager and two or more project engineers. Over the eleven years of study period, the core project team has averaged six people total, consisting of three project managers and three project engineers. The composition of the project team has varied over time due to staff turnovers. The core project team represents the all-round staff necessary to drive projects forward. Without the work performed by this staff, the project cannot proceed at all. All projects are subject to competitive bidding, which requires that they be advertised for bids by contractors who are interested in doing the construction work. The bid opening date is the day when bids submitted by contractors who are interested in doing the project are opened in public.

The contract is normally awarded to the contractor who submitted the lowest bid. The bid opening date also represents a due date that roughly identifies the end of design by the core project team and the handover of the project to construction. Projects may involve one or more contracts which are individual construction agreements with contractors to construct the projects designed by the core project team. Most projects only have a single contract, but a select few have more than one. Some projects are very large and therefore are divided into separate phases that would require multiple contracts to complete. Others are recurring in nature (often they are maintenance related) so new recurring contracts are generated on an ongoing basis. In cases where there are multiple contracts, a new design effort commences at some point after the recent design effort is completed and the project is handed over to construction.

Some projects have special requirements that cause them to require extra effort to complete. Often these requirements involve entities outside the core project team and therefore present an element of uncertainty and a lower degree of control over the project. These factors are referred to as dependencies which are discussed in more detail in a later section of this paper. Thus the core project team operates in a multi-project environment that is subject to dependencies that exert a degree of uncertainty on projects. The core project team is represented as the prime mover of a project as it begins its journey from an idea conceived by the CIP to its eventual completion as a fully formed tangible product in construction. The team, however, does not operate in complete isolation. There are internal and outside dependencies that interact with the core project team as a part of the project process. Dependencies are a measure of the extent a project is influenced by factors outside the system (in this case the core project team).

Project types

For the purpose of this study, projects are categorized into five types. *Major Roadway* projects are large roadway projects that often involve a complete reconstruction of a street. *Minor Roadway* projects are similar to the *Major Roadway* projects, but are smaller in scope and often involve only a half of a street or less. AC Overlay or the asphalt overlay project is a recurring large scale road resurfacing project that often covers ten to twenty streets per contract. Due to its immense size and its demand for resources, it is one project that is given a category of its own. *Sidewalk* projects are focused on repairing existing sidewalks and curbs. Miscellaneous is the catch-all category for other projects that do not fit the above categories. They consist of a variety of projects that include bridge retrofits, storm drains, parking lots, basketball/tennis courts, electrical, fuel tank removals, etc.

The "importance" of each project type is the relative priority given in terms of resource allocation. The *AC Overlay* project which has an importance level of 1 will trump any claims by other projects in terms of resources. The *Sidewalk* projects, which are considered fill-in projects, have the lowest importance score of 5. When choosing between two projects, the *Sidewalk* project will lose resources to the other types of projects. *Minor Roadway* projects will have priority over *Sidewalk* projects, but will lose resources if either an *AC Overlay* project or a *Major Roadway* project demands them. The resource allocation priorities are assumed to hold true except in cases when a due date forces resources toward a lower priority projects.

Dependencies

Resources transfers undoubtedly occur between projects all the time. Projects in this organization have relatively long durations that can span for years. Clearly each member is working on multiple projects simultaneously. The experience of having to shift time from one project to another is common among the core project team. Often the shift is in response to a due date. Other times, it may be an external dependency that drives resources towards or away from a project. As discussed in an earlier section, each project type has a level of importance that determines where resources are allocated in the event there is a scarcity.

The core project team interacts with other internal entities that include the city council, management, clerical staff, maintenance staff, planners, attorneys, accountants, and specialists that include landscape architects, traffic engineers and environmental specialists. All of these personnel may contribute in some way to a project. In most projects, the relationships with internal dependencies are generally cooperative so their involvement in the project seldom presents an impediment.

External dependencies are entities that exist outside the organization. They include the general public, permitting agencies, funding agencies, private property owners, regulatory agencies, utilities, outside technicians, and outside specialists. Some are hired directly by the core project team, like the outside technician and outside specialist, and therefore operate in a cooperative capacity. Other entities are either neutral or adversarial to the interests of the project. The five dependencies considered to have a significant influence on a project schedule include outside specialists, private property owners, utilities, permitting agencies, and funding agencies. Not all projects necessarily have these dependencies; there can be any number of combinations depending upon the nature of the project.

The need for outside specialists indicates that a project requires additional expertise beyond what is available within the core project team. In some cases, these needs are anticipated in advance and can be planned accordingly to minimize interruption to the project. In other cases, the need arises unexpectedly during the design process and requires the core project team to stop the planned work in order to address the new issue. One example, where there would be an unexpected need for an outside specialist, is the discovery of hazardous materials at the project site. Managing the removal and disposal of hazardous materials is not a task that the core project team is prepared to undertake and would require outside help.

Projects that require additional physical space in order to be constructed will go through a property acquisition procedure. This process involves real estate personnel to acquire properties in various forms including right of entry, easement, or fee (i.e., purchase of property). Depending on the type of acquisition, real estate personnel may have to negotiate with the individual private property owners to secure the needed area for construction. While the need to acquire the property can be anticipated early in the design process, what cannot be foreseen in advance is the outcome of the negotiations. It is possible for the property acquisition process to become prolonged if an agreement cannot be reached with the property owner within the planned timeframe.

If existing utilities conflict with the proposed construction work, the utility agencies that are responsible for the utility must be coordinated with. In some cases, the project will only require a minor work around in order to proceed with construction. In other cases, a utility company may have to do a project of their own in order to relocate the utility in conflict. Some examples of such utility coordination include utility pole relocation, water or sewer pipe relocation, and undergrounding overhead power and communication lines below ground. The need to address utility conflicts can be a source of interruption if it is not identified early enough in order to plan with the affected utility agency. In some well-remembered cases, a utility's chosen timeframe to respond to a conflict resulted in a prolonged interruption to several projects.

Projects that are expected to occur in areas under the authority of a permitting agency will require a permit before proceeding to construction. The need for the permit can be anticipated in advance, however, some permitting agencies may impose unexpected changes to the project or require more time than anticipated to review and approve a project. The delays in reviewing projects may be attributed to a shortage of staff at the permitting agencies.

Some projects receive their funding from outside funding agencies, including the federal government. These outside agencies will often have specific requirements on how the funding is used in the project. The federally funded projects in particular have an exhaustive amount of paperwork to track the usage of funds and to document the implementation and compliance of federal laws. Federally funded projects can affect a project by accelerating it by imposing an unanticipated deadline or delay it with a review period that extends beyond the planned schedule. One of the more frequent delays are due to environmental reviews, which project managers have often cited as the reason why certain projects could not advance for months or years.

Due Dates Requirements

The bid opening date represents the due date requirement for the projects. Given that the due dates have a relatively profound effect on the scheduled completion of the project and the resource loading distribution, it is worth mentioning how due dates are determined. First, funding deadlines are the most prominent among projects receiving outside funding. Most outside funding sources to their credit actually provide for reasonable timeframes to use the funding. The organization that has oversight on the federally funded projects does impose deadlines with seemingly little advance notice. These imposed deadlines are often the cause of accelerated schedules that force projects to proceed to construction at an earlier than anticipated date. Needless to say, additional resources must often be deployed to the project in order to meet these deadlines. Despite these imposed time pressures, federal funding is arguably the largest outside funding source for roadway projects and have made many large projects that would otherwise not happen, possible.

Secondly, seasonal deadlines come in a number of varieties and are driven primarily by changes in weather. Certain construction activities such as asphalt paving must be done while the ambient temperature is at a certain minimum. In most cases, the optimal season for paving is during the summer months when the weather is warm. To this end, construction is ideally scheduled so that paving occurs during the months that are warm, which further determines when bid openings must occur. Seasons also determine when birds migrate and nest in trees and can affect projects that involve the removal or pruning of trees. Under the Migratory Bird Treaty Act, no trees can be removed or otherwise disturbed while birds nest in the trees. Rainy seasons preclude grading and earthmoving activities that would contribute to erosion and runoff of material into the storm drains and eventually into major bodies of water. Finally, political deadline may come when an elected official promises, declares, or suggests that a particular project be a priority. A project that otherwise would have occurred at a later time may be accelerated to fulfill a desired political agenda.

Figure 2 presented above, shows the conceptual model that we are examining in the context of the research site. The project size is measured by number of core project team’s time consumed by the project. As discussed in the literature, the resource allocation to the project is likely to spike towards the due date (project deadline). The number of concurrent projects shows the intensity of competition for resources among projects. As described above, project type captures the nature of the work and more importantly the priority attached to the project while allocating resources. Finally, external dependencies could impact the project in number of ways as described above. We examine these relationships through empirical analysis, which is explained in the next section.

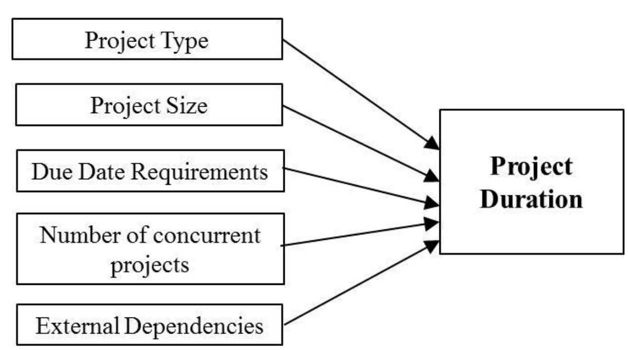

FIGURE 2. THE CONCEPTUAL MODEL.

VI. DATA, RESULTS OF EMPERICAL ANALYSIS AND OBSERVATIONS

The data includes a list of 65 projects that the core project team was responsible for over an eleven year period from 2000 through 2010. Each project contains a record of hours spent by the core project team on each project. The data is organized to show the total number of hours spent by the team per month over the course of a project's duration. Depending on the nature of the project, the duration of projects range from as short as 2 months to as long as over 164 months, hence project sizes vary considerably. Using the low bid construction price as a measure, projects varied from as low as $20 thousand to as high as $6 million.

The resource loading data is organized in a Gantt chart format on an Excel spreadsheet as shown in Table 1. The perspective of this data is from the point of view of an upper manager who is responsible for all members of the core project team and their projects. The chart lists all projects over the 11-year study period, with each project represented as a single project bar. The time horizon of the chart is the 11-year period from 2000 to 2010 divided into monthly increments. The project bar contains several numbers (one for each month). The numbers represent the number of hours reportedly spent by the core project team on the project for each month. Each project bar with its corresponding hours represents the design effort required to bring a project to its due date (the bid opening). The period immediately following the bid opening is the construction phase where the project is managed by the construction staff. While, the core project team does devote some hours during this construction period, the amount is usually nominal and is not considered as a part of this study's data.

TABLE 1. Resource Loading Data

	2003												2004											
Project #	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7808															11	11	5	0	0	0	0	0	0	0
7926																								
7944	0	15	7	1	22	52	11																	
7988																								
8120	0	1	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8130																								
8173	0	4	1	0	0	0	0	2	4	5	97	54	111	81	79	24	17	45	38	22	36	19	65	108
8178	162	186	189	170	226	140	145	130	141	186	73													
8195																								
8220	11	18	36	47	117	38	55	32	54	13														
8234																								
8236	27	77	46	5	22	29	18	1	1	9	24	46	19	28	58	12	10	0	0	0	66	150	0	65
8239	33	24	35	47	73	28	41	66	38	43	73	12	47	26	28	26	34	6	17	30	31	26	25	15
8240																								
8285																								
8289	7	6	52	34	43	36	18	64	35	16	11	3	11	7	2	14	57	62	9	22	0	5	1	0
8293																								
8321																								
8323	13	19	2	1	13	2	2	13	0	9	16	20	13	33	8	15	15	20						
8360																								
8363																								

Starting with the broader picture, charts were created to show the total staff time (i.e. the time spent by all six members of the core project team) reported to the project portfolio. Table 2 shows the number of staff hours consumed by the project portfolio over the eleven year study period. The immediate observation from the Table 2 is that the amount of total staff time spent (in hours) on the project portfolio is not constant. A common assumption used in project scheduling is the constant availability of resources over the time horizon evaluated. The data for this study indicates that the constant availability of resources is not usually the norm. The variability in the total staff time may be due to a few reasons. While core project team is primarily responsible for projects in the project portfolio, they also work on other projects in an assistant or advisory capacity. In addition there are also other administrative duties, training, and time away from the office that account for the variability. The distribution of total staff time appears to show abrupt spikes during certain times in the year. The spikes that appear to occur during the months of May and June are most likely attributable to the fact that construction ideally occurs during the summer months. This would lead the core project team to devote greater hours in the months leading up to summer to complete their projects. This leads us to the first observations.

Observations 1: *Availability of resources is not a constant. The resource availability varies due to seasonal factors and resource shifting to meet other organizational needs*

TABLE 2. Distribution of Total Staff Hours

	Year										
Month	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Jan	369	236	282	421	402	378	549	538	384	760	625
Feb	481	421	398	648	448	296	575	398	505	642	682
Mar	512	533	417	753	443	344	630	680	532	844	747
Apr	389	456	437	664	364	366	694	764	709	763	690
May	408	525	814	860	513	375	622	634	651	702	638
Jun	849	740	694	615	283	421	427	450	461	756	677
Jul	547	461	359	546	229	501	378	511	452	687	248
Aug	477	432	375	495	248	581	601	441	515	462	238
Sep	501	499	441	413	285	523	502	228	432	508	325
Oct	484	514	515	571	630	528	452	309	586	589	281
Nov	409	442	685	740	369	446	289	325	420	504	
Dec	390	457	427	452	311	413	408	339	587	496	
Total	5815	5715	5843	7176	4524	5172	6126	5617	6233	7712	5150
Average	485	476	487	598	377	431	510	468	519	643	515

The chart presented in Figure 3 shows the number of concurrent projects being worked on by the core project team on any given month. On average, the core project team worked on 18 projects simultaneously on any given month. The minimum number of projects worked on in a given month is 7, while the most the core project team had to work on in a given month was 25 projects. Interestingly, the number of projects has been trending downward. The trend may be a reflection of overall economy and the ability to fund new projects. Table 3 shows the descriptive statistics on the types of project included in the dataset. Also, resource distribution charts were created for all projects that began and completed within the project study period. Projects with only partial data due to the study period cutoffs were eliminated for this analysis. Figure 4 shows the resource distribution chart for sample projects of each type. The horizontal axis of each chart represents the duration of the project in units of month. The vertical axis is the number of hours reported by the core project team. All of the distributions clearly show that resource loading is not constant through the duration of each project.

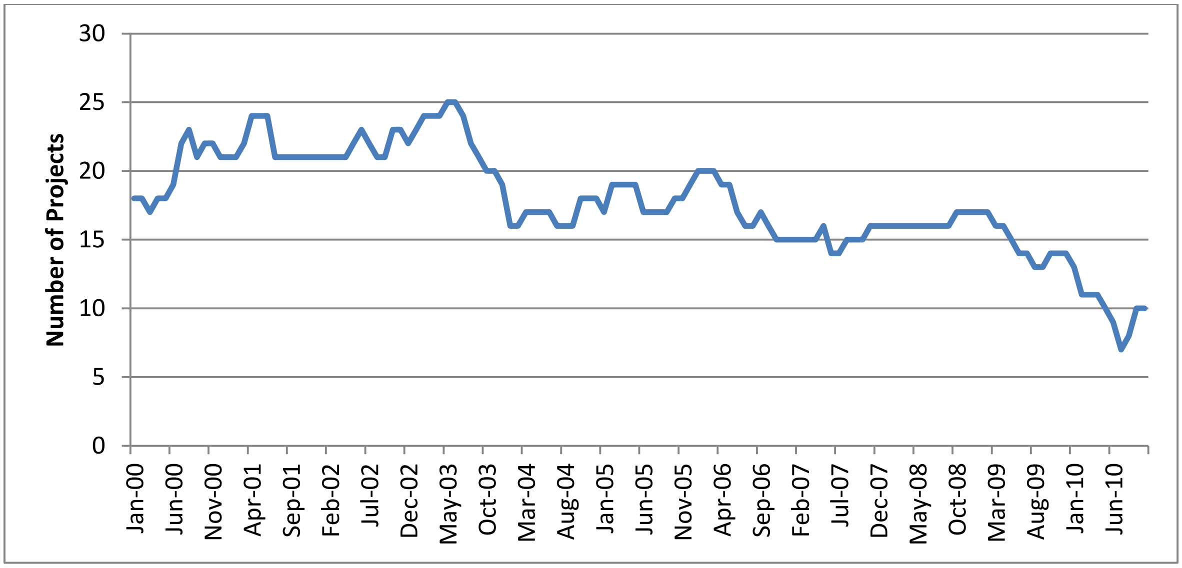

FIGURE 3. Number of Simultaneous Projects

TABLE 3. STAFF HOURS BY PROJECT TYPES.

Project Type	**Average resource used by project (in hours)**	**Average duration (in Months)**
Major Roadway	2,637	90
Minor Roadway	585	50
AC Overlay	4,927	59
Sidewalk	1,375	109
Miscellaneous	466	55

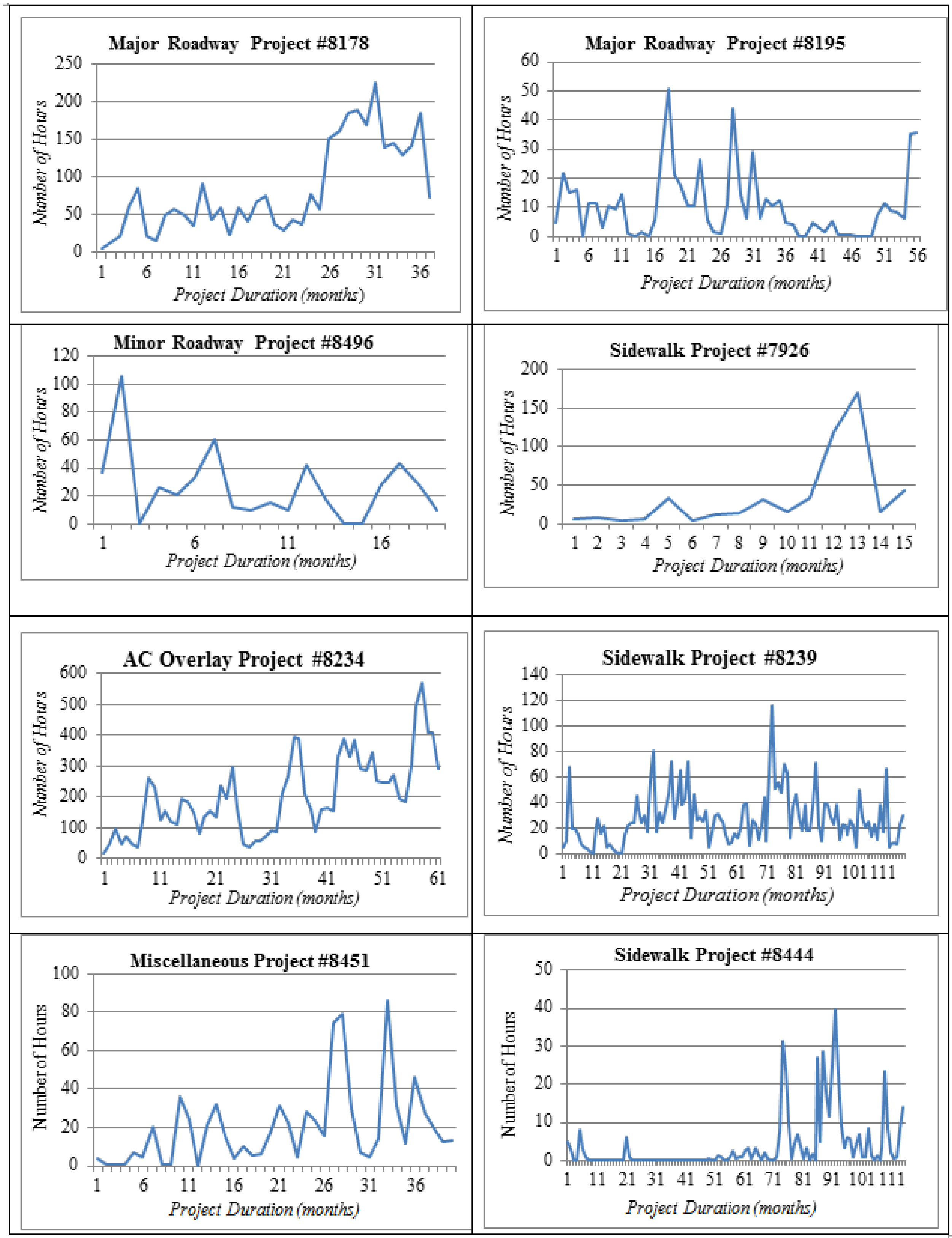

FIGURE 4. Resource Distribution Pattern of Sample Projects

Most *Major Roadway* projects are single contract projects. For most of these projects bid opening date occurs at the end of the project duration, which often results in an abrupt increase in resource usage. Other spikes in resource usage do occur at other points in the project duration as can be observed in project #8195. These spikes may be caused by due dates other than the bid opening as discussed in the next section. The *Minor Roadway* projects are considered less important compared with *Major Roadway* projects. One characteristic of these resource distributions are the relatively long periods of idle time. Similar to *Major Roadway* projects, spikes in resource usage do occur during the project.

The *AC Overlay* projects are large and demand an extraordinary amount of resources. For this reason, it is given a category of its own. The project is a multi-contract project with an average of one construction contract per year. With the approach of each bid opening, there does appear a spike in resource usage as would be expected. Most *Sidewalk* projects are recurring projects with contracts being advertised continually. Some projects, despite being considered recurring, have had only one contract within the study period, which give the resource distribution the appearance of a single contract project. Project #7926 above is an example of such project. The Sidewalk projects have periodic spikes that can be attributed to the recurring bid opening dates throughout its duration. Some projects show extended periods of idleness such as project #8444 above. In general, *Sidewalk* projects are considered fill in projects that are allocated resources when available.

As the category would imply, *Miscellaneous* project resource distribution are not easily generalized. The category consists of a variety of project of differing level of scope and importance. A large number of very small projects with very short durations fall into this category. If further research were to be done on this subject, additional refinements to this category could be considered to separate projects by level of importance. The analysis of the resource distribution charts and the descriptive statistics of the project types lead us to the following observations.

Observation 2a: *Project Size (measured by number hours of engineering spent) and project duration (measured in months) vary considerably for projects in the portfolio*

Observation 2b: *Resource loading during a project's life is not constant.*

Observation 2c: *Due date nervousness does have a noticeable effect on the amount of resources allocated as a project nears a deadline.*

Regression Analysis

We analyzed the relationship between the project duration and the independent variables that may influence the duration (as shown in the conceptual model) using Linear Regression models. The dependent variable in the regression model is the project duration from the commencement of design to the bid opening date (or due date). We developed five different regression models and the results of these models are summarized in Table 4.

Model 1: The number of hours required to complete the project (which signify the project size) is the only independent variable in this model. The p-value 0.0035 indicates that this variable is statistically significant. Naturally, the greater the number of hours required to complete the project, the longer the expected duration. However, the R-Square value of 0.1642 indicates a low proportion of the variability in the project duration is explained by the number of hours required by the project. Reflecting back on the resource distribution charts, we observed that some projects exhibited idle periods when little to no hours was spent. Given that these idle

TABLE 4. Results of Linear Regression Models

Category	Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	Intercept	39.13	38.31	-197.92	171.61	-167.21
Project/ Portfolio	Project Hours	0.0083 ***(0.0035)***	0.0083 ***(0.0044)***	0.0210 ***(0.0002)***	0.0156 ***(0.0190)***	0.0155 ***(0.0069)***
	Simultaneous Projects		0.0414 *(0.9859)*			
Project Types	AC Overlay ***(is the base case; dropped from regression)***					
	Major Roadway			216.68 ***(0.0014)***	186.31 ***(0.0142)***	191.99 ***(0.0029)***
	Minor Roadway			236.44 ***(0.0018)***	209.10 ***(0.0141)***	205.59 ***(0.0044)***
	Sidewalk			232.68 ***(0.0020)***	211.34 ***(0.0114)***	207.02 ***(0.0039)***
	Miscellaneous			222.68 ***(0.0037)***	182.31 ***(0.0319)***	188.18 ***(0.0103)***
External Dependencies	Outside Specialist				11.7817 *(0.4098)*	
	Property Acquisition				14.1047 *(0.5467)*	
	Utility Coordination				17.1446 *(0.3447)*	
	Permit				11.8565 *(0.4084)*	
	Federal Funding				28.9962 *(0.1274)*	37.32 ***(0.0162)***
Model fit	R Square	0.1642	0.1642	0.3783	0.5071	0.4573
	Adjusted R Square	0.1468	0.1286	0.3076	0.3807	0.3816

Note: (1) numbers in italic and in () are the p-values, (2) p-values in bold are statistically significant

periods exist, we know that it is possible for duration to become extended without significant hours being spent. This leads us to our third observation.

Observations 3: *The number of hours required by project (project size) has statistically significant impact on duration but it explains a very small portion of the variability in the project duration.*

Model 2: The second variable of interest in our study was the number of Simultaneous (concurrent) Projects that was in portfolio. The variable is the average number of other projects that occurred simultaneously as the project of interest was in the portfolio. This variable is intended to account for the hours other projects that take away from the project of interest or the level of competition for resource that exists when projects was in the portfolio. This model included two independent variables: *Project Hours* and number of *Simultaneous Projects*. The *Simultaneous Projects* is a very high p-value, which indicates that this variable is not statistically significant. Further, the R-Square value of 0.1642 suggests that the *Simultaneous Projects* variable does not improve the regression model any more than using Project Hours alone. Given this result, the *Simultaneous Projects* variable is discarded from further analysis. This counter intuitive result is summarized in the next observations.

Observations 4: *The number of Simultaneous Projects variable does not have significant impact on the project duration*

Model 3: Continuing with the analysis, we include the additional independent variables pertaining to the project types as shown in Table 4. Including the additional variables do improve the R-Square from 0.1642 to value to 0.3783 (adjusted R-Square from 0.1468 to 0.3076), which is an improvement in the model fit. The Project Type variables is a partial reflection of the nature of work entailed, the priority attached in resource allocations and internal dependencies. Since project is classified as one of the five types, we need to set one project as the base case. We excluded *AC Overlay* project type from regression, thus it is the base case. The Model 3 results show that all the four project type variables "*Major Roadway, Minor Roadway, Sidewalk and Miscellaneous*" are statistically significant. Also the coefficients associated with the four project types are bigger positive number, thus project duration is increased for the four project types as compared to the project type *AC Overlay*. This result clearly shows higher relative priority given in terms of resource allocation as captured by *Project Type* has huge impact on the project duration.

Observations 5: *The Project Type (relative priority given in terms of resource allocation) has significant impact on the project duration.*

Model 4: We added all the external dependency related variables to the analysis in this model. The R-Square value increased to 0.5071 but the improvement in adjusted R-Square is small (about 8%). Also, we notice that all the external dependencies related variables the Model 4 are statically not significant. A backward stepwise regression is applied to improve the reliability of the model by excluding one variable at a time. The result of this stepwise regression takes us to Model 5.

Model 5: Discarding the variables does cause the R-Square value to decrease slightly to 0.425 however the adjusted R-Square value increased slightly. Also, the remaining variables yield a p-value of less than 0.05. The *Project Hours*, the four project types and the external dependency, "*Federal Funding*" appear to be the dominant factors affecting project duration. Of the variables representing external dependencies, Federal Funding proved to be the factor that affected duration the most. Given the start and stop nature of federally funded projects, due to funding deadlines, it appears to make sense that the duration of such projects would be adversely affected. These results lead us to the final two observations.

Observations 6: *The Federal Funding requirements (an external dependency) has significant impact on the project duration.*

VI. CONCLUSIONS

Our aim in this research was to identify factors influencing project duration in multi-project environments. As discussed, estimation (forecast) of the project duration before adding the project to an existing portfolio has significant value in planning stages. We were able to draw interesting observations in this exploratory research that has significant impact on multi-project planning. Prior studies on this topic were done in the context of single project management settings, and reported that the project size as measured by the number of labor hours determined the project duration to a large extent. We find that project size (number of labor hours) accounts for only 16% of the variability in the project duration.

The magnitude of the impact of multi-project environment factors such as project prioritization (as measured by project type) and the external due date requirements (attached to federal funding) was much bigger than the number of engineering hours. The project prioritization (as measured by project type) explained approximately 21% of the variability in project durations. In our study, we found that the *AC Overlay* was given the top priority by the agency and it increased the project durations of all the remaining four types of project significantly. We had conversation with the upper manager who is responsible for all members of the core project team and their projects, to better understand why *AC Overlay* got the highest priority. The following three observations were derived from our conversation. First, *AC Overlay* is related to recurring road maintenance, and the road pavement condition is used as an important performance measure in comparing road condition across cities. Hence, this project type gets highest importance from organizational and political point of view. Second, the AC Overlay projects are large projects with high impacts, thus stakes are high. Finally, delay in road maintenance projects may lead to severe damages and increase in long-term road maintenance costs. The reasoning behind prioritization and the understanding of external dependencies are essential in multi-project situations to generate a good estimate for the duration of future projects.

This research is the first attempt to examine issues related to estimating construction project durations in multi-project settings. Although the findings are interesting, the observations are based on only one multi-project context pertaining to engineering and construction. Further, our model explained only 42% of the variability in the project durations. It is likely a number of other factors may have influence the project duration. Replication of this study in other construction/engineering settings and in other industry segments is required to ascertain our findings and generalize the observations. In-spite of the limitation, this work identified an interesting and promising area of research that has significant managerial implications.

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