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EFFICIENT RESOURCE PLANNING FOR INFRASTRUCTURE PROGRAMS

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ABSTRACT

This paper investigates the effectiveness of various resource planning options on the duration and cost of construction / maintenance operations in large infrastructure networks such as buildings, highways, bridges, and water/sewer networks. The investigation utilizes a generalized scheduling model that suits multiple distributed sites with non-typical tasks and work conditions. The scheduling model also employs an information system to store data related to various work sites, tasks' optional construction methods, and available resources. Using this scheduling model on an example project, 800 scheduling experiments were conducted using various planning options: site scheduling order, staggered versus parallel crews, crew movement time/cost, and site productivity conditions. Based on these experiments, site order, crew moving, and site productivity are found to have a significant impact on schedule and have to be considered in developing realistic plans. Suggestion to improve crew scheduling are then made.

KEY WORDS

Construction Management, Infrastructure, Resource Planning, Repetitive Projects, and Computer Applications

1. INTRODUCTION

Today, more than ever before, the world faces significant infrastructure problems. Aging infrastructure needs to be repaired, upgraded, replaced, or expanded. Common characteristics of these projects are being huge in size, complex, involve many repetitive activities that can be spatially distributed, and require large amount of resources for their construction/maintenance. In addition, with the prevailing privatization pressures, municipalities and contractors strive to conduct operations in a timely and cost effective manner, with minimum service interruption to the public through efficient use of resources.

Traditionally, detailed execution plans for infrastructure projects are determined based on experience on previous work. This, however, represents a major challenge for construction managers since maintenance operations for infrastructure networks are usually carried out under stringent resource and time constraints. Most maintenance operations for municipal highway networks in Canada, for example, are carried out only during the mild spring/summer season. Similarly, maintenance operations for schools are carried out during the short summer vacation. In some industrial facilities, also, a costly shutdown of plant during maintenance is a normal procedure.

As compared with traditional projects, planning the construction/maintenance operations in infrastructure projects is a much bigger challenge, for the following reasons:

- Multi-site distributed work: with the multi-site nature of infrastructure networks, the proper number of crews and their routing order among the sites have to be optimally decided, considering the time and cost to move crews from one site to the other;

- Varying work conditions: due to the large and distributed nature of infrastructure networks, local work conditions, including weather, vary from one site to the other. Such local conditions are important to consider in the plan and accordingly schedule the work of each site at the time in which work productivity is highest; and

- Stringent constraints: as mentioned earlier, infrastructure projects are usually carried out under stringent resource and time constraints.

As such, the number of crews to use, the construction method to employ in each task, the varying nature of work at each site, and the site order represent key decisions that relate particularly to infrastructure projects.

Most of the planning and scheduling tools available at the commercial and research levels address some but not all aspects of infrastructure project management. Almost all commercial project management software systems, for example, are based on the Critical Path Method (CPM) and, as such, exhibit some serious drawbacks. Despite of their multi-project and resource leveling capabilities, they are mainly duration-driven, are not formulated to plan backwards from a given deadline and resource limits, and do not guarantee crew work continuity (Reda 1990; Suhail & Neale 1994). In addition, their schedule presentation does not legibly show the large amount of data involved in large projects or the resource movements throughout a construction program. These limitations are mainly due to inadequate resource management, which is crucial for infrastructure projects.

To consider for the scheduling needs of infrastructure projects, a new scheduling algorithm (Hegazy 2001) has recently been introduced as a resource-driven model that facilitates the planning of resources in distributed and repetitive projects. The model is flexible and considers all project parameters as variables to be optimized using the Genetic Algorithms (GAs) technique. The model has been implemented in a computer program (BAL) that is used in the present study.

In this paper, various resource-planning strategies are experimented with using BAL program and the results analyzed to examine the schedule characteristics under different resource planning options.

2. EXAMPLE CONSTRUCTION PROGRAM

A hypothetical example of a pavement maintenance program is used for the present analysis. The pavement program involves 15 sites with varying local conditions (i.e., productivity factors) and different work quantities. The general information for the example is shown in Table 1.

Table 1: General Information of the Example Maintenance Program

Number of Sites	15
Deadline Duration	60 days
Indirect Cost	\$5,000 / day
Liquidated Damages	\$20,000 / day
Incentive	\$2,000 / day
Crew Moving Cost among Sites	\$10 / km
Crew Moving Speed among Sites	16 km/day

2.1 Construction Sites

The 15 sites used in this example are taken from three different localities in Southern Ontario, Canada: Toronto; Barrie (about 100 km north of Toronto); and Kitchener-Waterloo (about 120 km west of Toronto). Each site is given a code that defines its number and locality (e.g., T1 to T5 in Toronto; B1 to B5 in Barrie; and KW1 to KW5 in Kitchener-Waterloo), as shown in Figure1. All information related to site locations and local productivity factors (entered as monthly values that depend on weather, site access, and other factors) are listed in Table 2. It is noted here that the sites in Barrie area have low productivity in winter months.

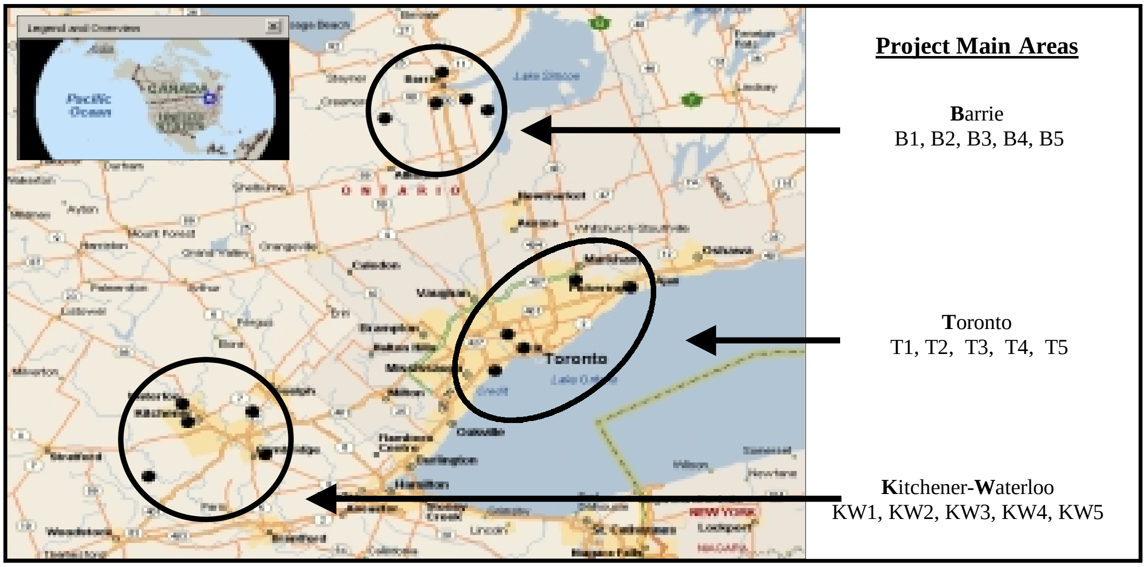
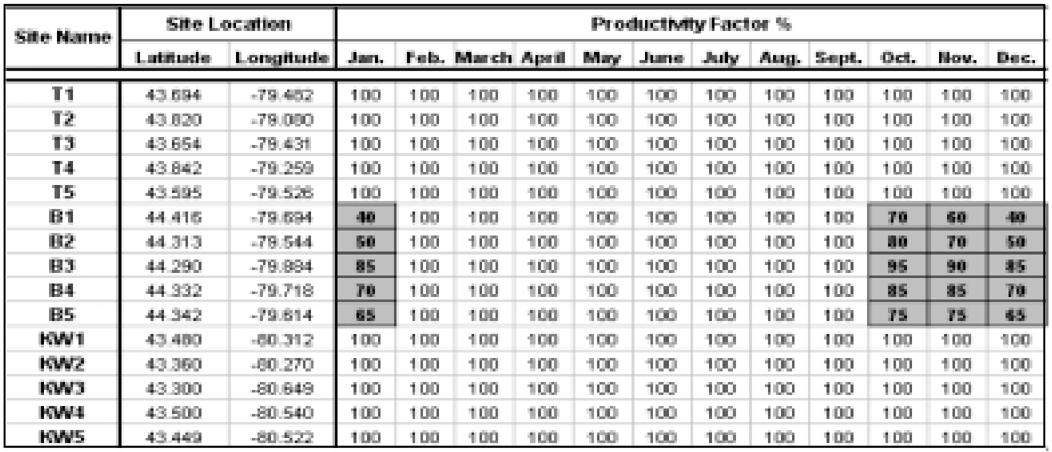


Figure 1: Sites Locations

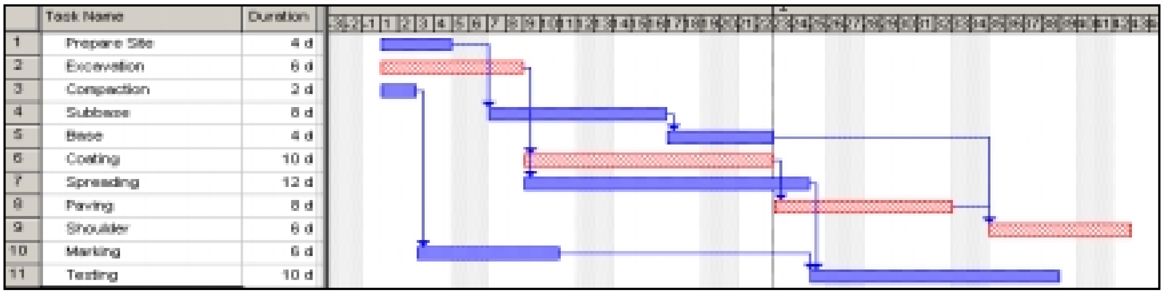
Table 2: Sites Locations and Productivity Factors



Site Name	Site Location		Productivity Factor %											
	Latitude	Longitude	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
T1	43.694	-79.452	100	100	100	100	100	100	100	100	100	100	100	100
T2	43.820	-79.080	100	100	100	100	100	100	100	100	100	100	100	100
T3	43.654	-79.431	100	100	100	100	100	100	100	100	100	100	100	100
T4	43.842	-79.259	100	100	100	100	100	100	100	100	100	100	100	100
T5	43.595	-79.526	100	100	100	100	100	100	100	100	100	100	100	100
B1	44.416	-79.694	40	100	100	100	100	100	100	100	100	70	60	40
B2	44.313	-79.544	50	100	100	100	100	100	100	100	100	80	70	50
B3	44.290	-79.884	85	100	100	100	100	100	100	100	100	95	90	85
B4	44.332	-79.718	70	100	100	100	100	100	100	100	100	85	85	70
B5	44.342	-79.614	65	100	100	100	100	100	100	100	100	75	75	65
KW1	43.480	-80.312	100	100	100	100	100	100	100	100	100	100	100	100
KW2	43.360	-80.270	100	100	100	100	100	100	100	100	100	100	100	100
KW3	43.300	-80.649	100	100	100	100	100	100	100	100	100	100	100	100
KW4	43.500	-80.540	100	100	100	100	100	100	100	100	100	100	100	100
KW5	43.449	-80.522	100	100	100	100	100	100	100	100	100	100	100	100

2.2 Construction Activities

The activities involved in a typical site and their logical relationships are shown in Figure 2. For the present example to be close to reality, the quantity of work is varied at some sites (a zero quantity means an activity does not exist at a site). For simplicity, all activities in all sites are standardized, except for sites B2 and KW1 in the “Prepare Site” activity. The work quantity and available construction methods for the activities in standard sites are shown in Table 3. Also, the work quantity and available construction methods in the non-standard sites (B2 and KW1 of activity “Prepare Site”) are shown in Table 4.



	Task Name	Duration
1	Prepare Site	4 d
2	Excavation	8 d
3	Compaction	2 d
4	Subbase	8 d
5	Base	4 d
6	Coating	10 d
7	Spreading	12 d
8	Paving	8 d
9	Shoulder	8 d
10	Marking	6 d
11	Testing	10 d

Table 3: Work Quantity and Available Construction Methods in Standard Sites

Activity	Standard Sites	Standard Quantity	Available Construction Methods
Prepare Site	All except B2 and KW1	400	Md1
Excavation	All	600	Md2, Md3, Md4
Compaction	All	250	Md5
Sub-base	All	1400	Md6
Base	All	500	Md7
Coating	All	50	Md8
Spreading	All	1	Md9, Md10, Md11
Paving	All	1	Md12, Md13, Md14
Shoulder	All	1	Md15
Marking	All	1	Md16
Testing	All	1	Md17, Md18

Table 4: Non-Standard Sites

Site	Activity	Quantity	Construction Methods
B2	Prepare Site	1000	Md4
KW1	Prepare Site	300	Md2

2.3 The Schedule

The data of the example program was entered into program BAL to prepare for the analysis. Once entered, BAL produced a construction schedule as shown in Figure 3. The figure shows the critical path on the top pane and any other network path at the bottom pane. Total project duration and cost are circled and crews are shown in colors. It is noted that the initial site order is the one entered by the user.

3. DISTRIBUTED SCHEDULING: EFFECT OF SITE ORDER

With the scheduling model uniquely considering multiple scattered sites, changing the site order becomes an essential variable that is ignored in all other scheduling models. It is important; therefore, to study how cost components can be affected by that variable, and also the impact on total project duration.

It is noted that the number of crews in each activity, the method of construction used, and work interruptions are fixed in this study and were determined using the scheduling model, based on project deadline. As such, the present analysis focuses only on the unique aspects of the scheduling model, mainly site order, crew movement, crew staggering, and site productivity factors.

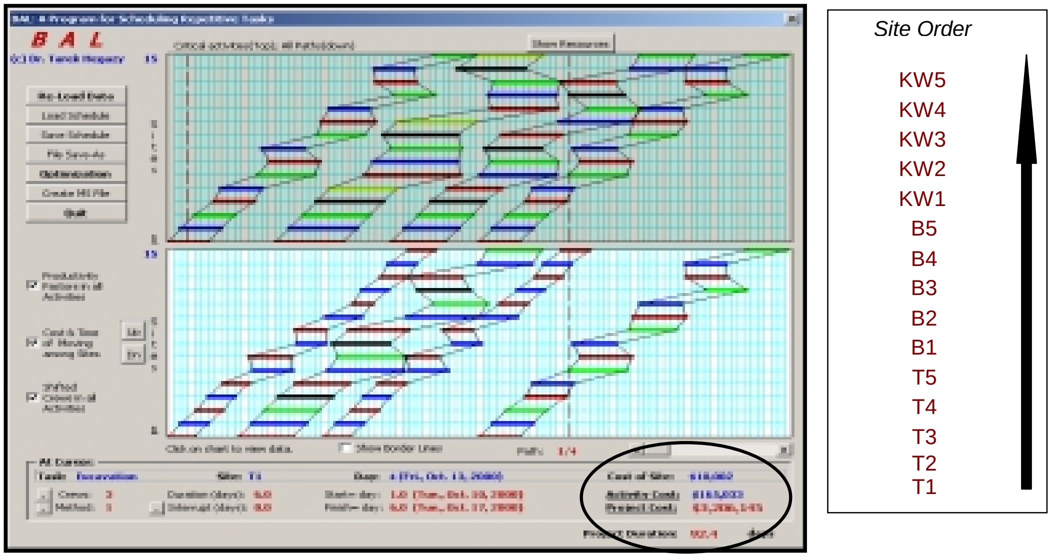


Figure 3: Initial Schedule

3.1 Effect of Changing the Site Order

As shown in Fig. 3, initial duration was 92.4 days, with a total cost of $3,206,145. These two values are directly affected by the site order, which has a direct impact on various aspects such as crew movement time/ cost and the schedule sensitivity to site productivity factors. For example, Figure 4 shows a new schedule in which a different site order is used. Duration became 112.9 days, with a total cost of $3,739,841. In the revised schedule of Figure 4, the increased project cost is due to the difference in moving cost and productivity factors.

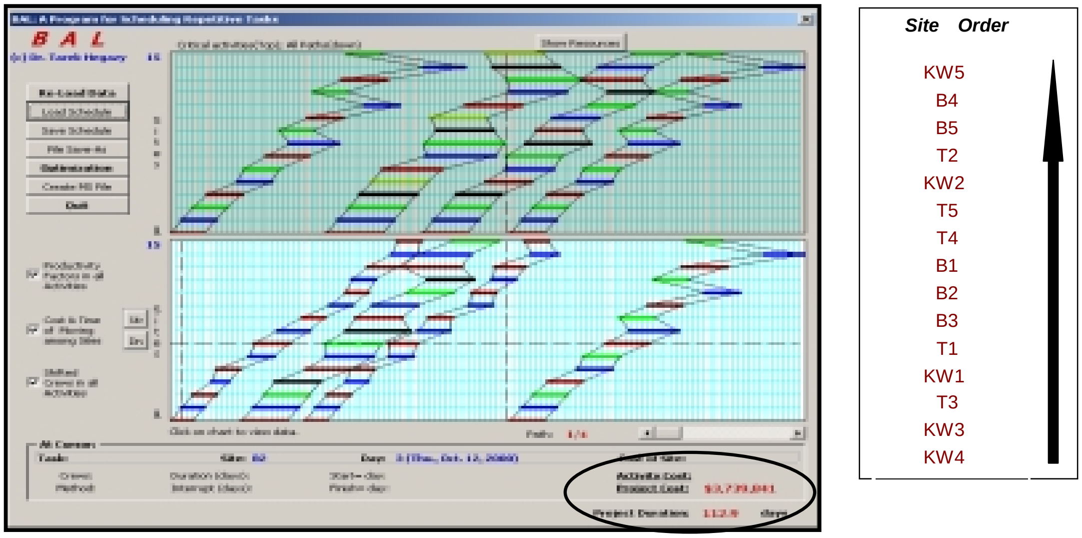


Figure 4: A New Schedule with a Different Site Order

3.2 Quantifying the Impact of Changing the Site Order

When the site order is varied, the schedule changes due to the change in crew moving time/cost and the cost due to productivity factors. The schedule also becomes sensitive to whether the crews are staggered or parallel. To consider the effect of these factors, individually or combined, various combinations of factors are listed in Table 5, with each combination being represented by 3 letters for crew staggering, crew moving, and site productivity.

Table 5: Different Combinations of Scheduling Options

Case	Abbr.	Crew Staggering	Consider Crew Moving	Consider Site Productivity
1	SMP	Yes	Yes	Yes
2	SM_	Yes	Yes	No
3	S_P	Yes	No	Yes
4	S_ _	Yes	No	No
5	_MP	No	Yes	Yes
6	_M	No	Yes	No
7	_ _P	No	No	Yes
8	_ _ _	No	No	No

Before starting the analysis, 100 random site orders were generated and the consequent project duration and cost for each order was determined using program BAL. For each of the 100 site orders, 8 scheduling experiments (as per Table 5) were carried out and the results recorded. As a compilation of the 800 experiments conducted, the maximum, minimum and average durations and costs for each combination are shown in Table 6. As demonstrated by the wide range of values obtained for program duration and cost, the schedule is confirmed to be highly sensitive to site order and the combination of factors.

Table 6: Maximum, Minimum, and Average Duration and Cost Results for all Combinations

		SMP	SM_	S_P	S_ _	_MP	_M_	_ _P	_ _ _
Dur.	Min.	86.4	75.4	69.8	61.6	89.2	79.8	75.4	70.0
	Ave.	104.8	91.7	84.1	67.6	108.3	95.6	87.6	74.7
	Max.	129.6	117.5	112.7	90.0	135.0	122.8	109.4	90.0
Cost	Min.	3072422	2631052	2598975	2255684	3166503	2742635	2764844	2465684
	Ave.	3549142	3049551	2996210	2405784	3629176	3146652	3065562	2583684
	Max.	4178743	3962033	3954737	2965684	4452944	3820022	3634450	2965684

4. CREW PLANNING STRATEGIES

Several factors are uniquely considered in the present scheduling model, such as site order, crew movement time/cost among sites, local site conditions, and parallel versus staggered crew assignment. These factors represent planning options that greatly impact the time and cost of a schedule.

4.1 Analysis of Crew Staggering Strategy

As shown in Table 5, the four cases that involve crew staggering strategy are SMP, SM_, S_P, and S_ _ (Baseline case). Figure 5 presents the analysis of crew staggering strategy, combined with moving, productivity, and both, respectively. The results show the significant effect of considering crew moving and site productivity. For example, even the schedule associated with the best site order gives a 14.35 % increase in project duration when crew moving is considered. As noticed, the increase in duration and cost is highest when both crew movement and site productivity are considered. Their effect also tends to be cumulative, as shown in part (c) of Figure 5. Accordingly, crew moving and site productivity have significant impact and cannot be ignored in the scheduling process. A summary of the individual and combined impact on time and cost is shown in Table 7.

4.2 Analysis of Parallel Crews Strategy

The same approach is applied to analyze the parallel crew strategy, _MP, _M_, _ _P, and _ _ _ (Baseline case). The results related to this strategy are summarized in Table 8. In this strategy, both crew movement and site productivity cause significant impact on project duration and cost.

Table 7: Summary of Results for Crew Staggering

Consider	Crew moving alone (SM_)		Site productivity alone (S_P)		Both (SMP)	
	Duration	Cost	Duration	Cost	Duration	Cost
Ave. Increase	35.62%	26.76%	24.37%	24.54%	54.96%	47.53%

Table 8: Summary of Results for Parallel Crews

Consider	Crew moving alone (_M_)		Site productivity alone (_ _P)		Both (_MP)	
	Duration	Cost	Duration	Cost	Duration	Cost
Consider	27.90%	21.79%	17.21%	18.65%	44.93%	40.47%

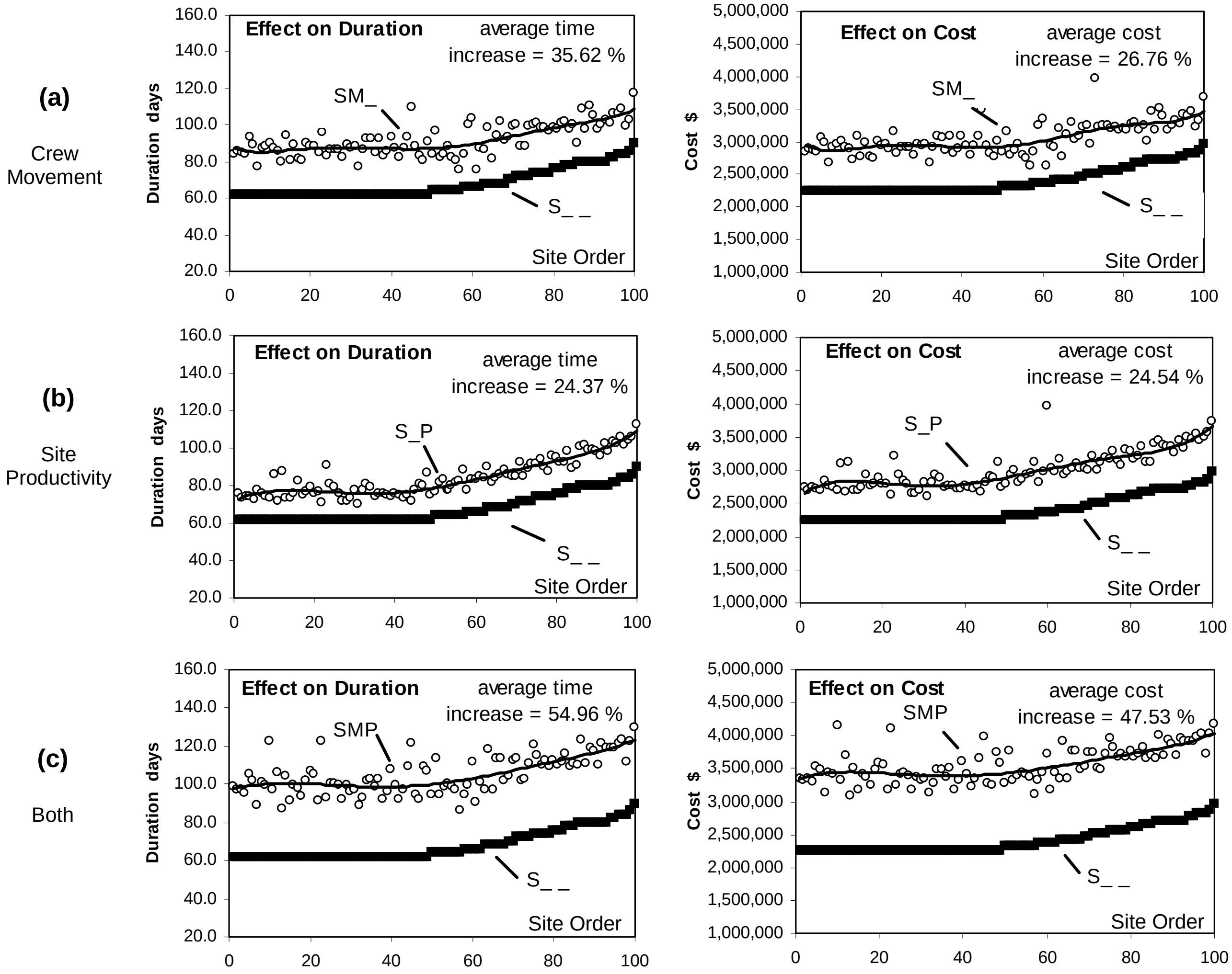


Figure 5: Crew Staggering Strategy

4.3 Comparison Between Staggered and Parallel Crews

As a comparison between the two main strategies, parallel crews and staggered crews, results are plotted considering crew movement, site productivity, and both. In general, using staggered crews was found to provide better schedules, that is, for the same site order, lower duration and cost. To quantify the difference between staggered and parallel crews, Figure 6 was plotted and the average improvement due to applying crew staggering was calculated. When both crew movement and site productivity are considered, for example, crew staggering leads to an average of 3.37% reduction in duration and 2.29% reduction in cost.Table 9, summarizes the results of the comparison. From these results, it is wise to use crew staggering as a simple and efficient strategy to improve schedules.

Table 9: Duration and cost Improvement due to Crew Staggering

	Crew moving alone (_M_)		**Site productivity alone (_ _P)**		**Both (_MP)**	
	Duration	**Cost**	**Duration**	**Cost**	**Duration**	**Cost**
Improvement	4.24%	3.18%	4.16%	2.31%	3.37%	2.29%

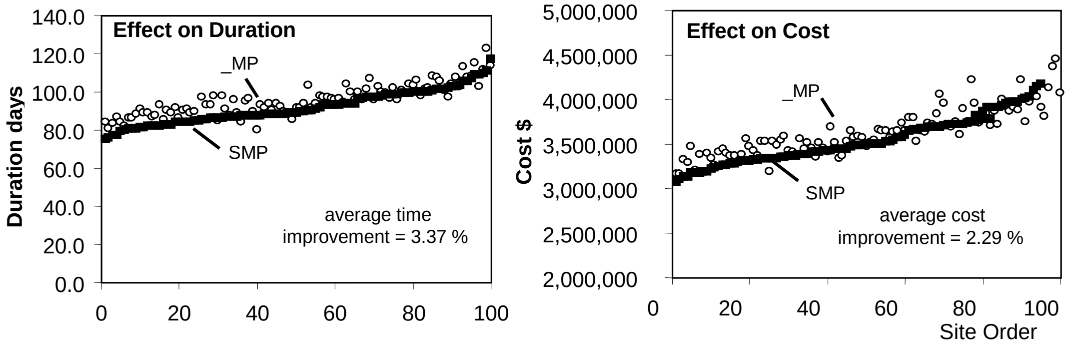


Figure 6: Comparison between Parallel Crews and Staggering Crews, Considering both Crew Movement and site Productivity.

5. SUMMARY AND CONCLUDING REMARKS

In this paper, 800 scheduling experiments were conducted using a distributed scheduling model to analyze the impact of various planning and crews assignment options on project duration and cost. It was found that the site order substantially affects project duration and cost, particularly when crew moving and site productivity factors are considered. As a conclusion, current scheduling models that ignore these three significant factors end up with very optimistic schedules that do not reflect reality, thus being vulnerable to problems and changes during construction. The paper demonstrated the importance of the new scheduling model presented and the importance of considering how crews are assigned to the various sites so that practical schedules are developed, particularly for multi-site infrastructure construction/maintenance operations.

6. REFERENCES

Hegazy, T. (2002). Computer-Based Construction Project Management. Prentice Hall, Upper Saddle River, NJ, USA.

Hegazy, T. (2001). "CPM/LOB Model for Efficient Scheduling of Repetitive Construction Projects". Proceedings of the 8th Annual Canadian Construction Research Forum, Kananaskis, AB.

Reda, R. (1990). “RPM: Repetitive Project Modeling”. *Journal of Construction Engineering and Management*, ASCE, Vol. 116, No. 2, pp. 316-330.

Suhail, S. and Neale R. (1994). “CPM/LOB: New Methodology to Integrate CPM and Line of Balance”. *Journal of Construction Engineering and Management*, ASCE, Vol. 120, No. 3, pp. 667-684.