BETTER VISUALIZATION FOR MULTIPLE-SITE INFRASTRUCTURE PROGRAMS USING GIS

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Abstract

This paper introduces a model for optimizing and visualizing infrastructure maintenance programs of multiple-distributed sites. Two unique aspects of the model are discussed in the paper: the underlying Geographic Information System (GIS); and the powerful scheduling engine that optimizes execution plans. The GIS system stores and represents two main levels of information about the scattered sites involved in a construction/maintenance program. The first level pertains to pre-planning data such as resources, locations, optional estimates, and work constraints. This information is then used by the scheduling engine to generate an optimum schedule, and accordingly, a second layer of GIS information is generated containing activities' start and finish dates and the assigned crews. This layer of information is then used by the GIS system to visualize the crews' work assignments in a legible manner. An implementation program BAL is presented on an example application to illustrate the benefits of using GIS to support municipalities and owner/contractor organizations administering large number of infrastructure assets, such as buildings, highways, and bridges, etc.

Keywords: infrastructure, GIS, scheduling, optimization, resource management

Introduction

In recent years, interest in developing management systems for infrastructure networks, such as highways, bridges, airports, and water/sewer systems, etc., has grown rapidly to help sustain infrastructure services. Management systems concern mainly with prioritizing capital assets for maintenance and repair (M&R) purposes. The majority of management systems, however, provide little or no decision support during the execution of M&R programs, thus leading to cost overruns and delays. Among the biggest challenges facing the execution planning of M&R programs is the repetitive multiple-location nature of M&R programs and the difficulty in representing the large amount of information involved.

Currently, there exist many software tools for maintenance management. Some of these systems may provide traditional planning and scheduling features such as bar charts to schedule operations. While these systems are beneficial, they address some but not all aspects of infrastructure execution planning. They are not formulated to respect a given deadline and do not consider the distributed and repetitive nature of operations. In addition, they provide no decision support for cost optimization and do not legibly represent the large amount geographically dispersed data, particularly related to the assignment of resources among the sites. As such, the need has emerged for a new decision support tools that use GIS technology to support effective management of infrastructure M&R programs with multiple sites.

This paper provides details on the use of GIS technology to facilitate the development of a generalized model for optimizing and visualizing M&R programs that involve distributed sites. An example application is then used to illustrate implementation issues.

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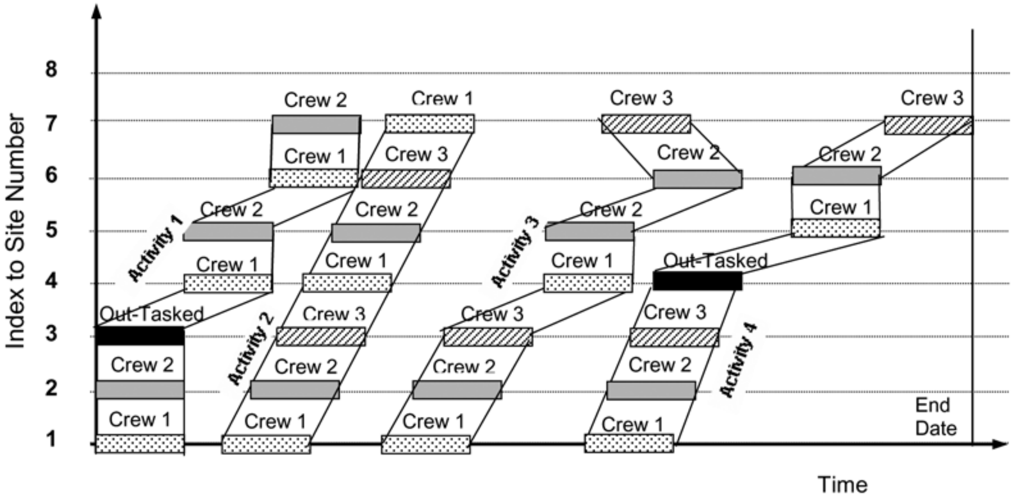


Fig. 1. Multiple-site schedule representation.

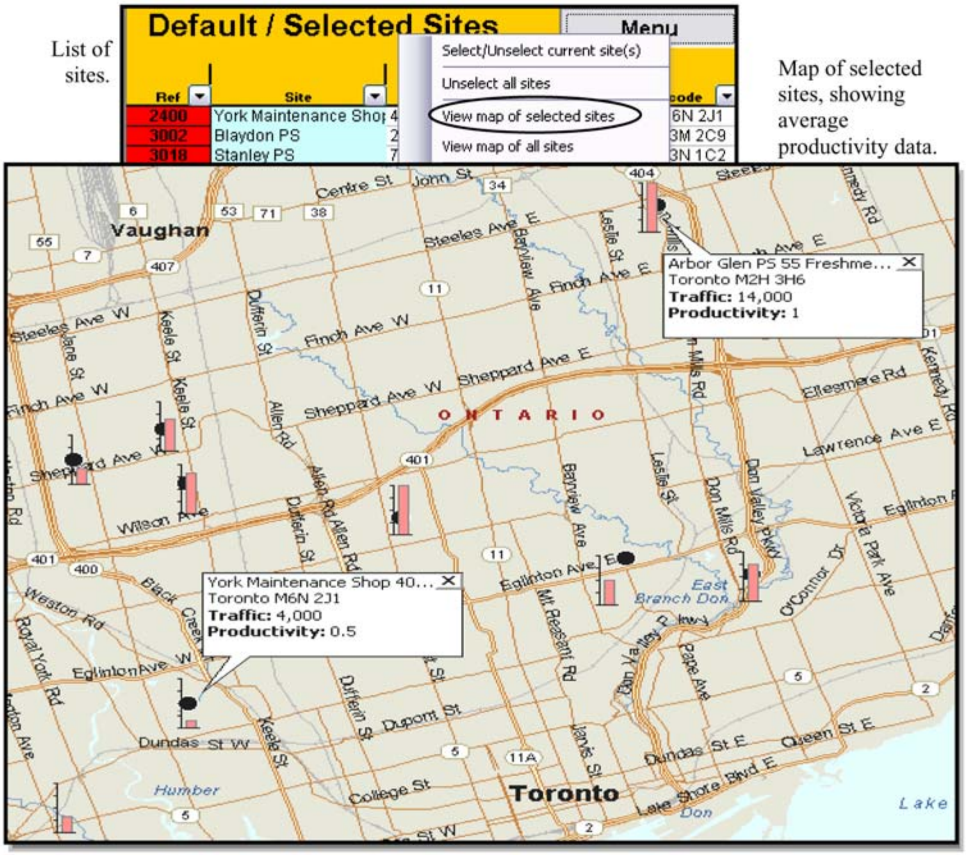
Geographic Information Systems (GIS)

Simply put, GIS is an information system that combines layers of information about a place to provide better information about that place. A GIS involves hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modelling and display of spatially-referenced data.

A GIS is not an automated decision making system but a tool to query, analyze, and map data in support of the decision making process. For example, GIS can be used to help reach a decision about locating a new housing development in an area having minimal environmental impact and is also close to a population center. GIS presents information quickly, concisely, and clearly in the form of maps to facilitate efficient analysis of multiple decision scenarios. Presenting information in maps also well suits the powerful pattern recognition capability of human beings who can draw conclusions from maps much easier than from tables of rows and columns. Based on this description of GIS technology, it is clear that it has great potential to support execution planning decisions for multiple-site infrastructure M&R programs.

Distributed Scheduling Model

Recently, a new Distributed Scheduling Method, DSM, was introduced to facilitate the planning of resources in distributed and repetitive projects (Hegazy et al., 2004), and was implemented in a computer software program, called BAL. The DSM helps in scheduling multi-site M&R programs that are delivered using combination of in-house resources and outsourcing. The DSM model determines the optimum site execution order and assigns available resources to the various sites in a manner that maintains crew work continuity, and meets the cost, and resources constraints. To meet deadlines, speedy delivery options (often expensive) for various activities are stored and used in the scheduling process. One of the key features of the DSM is its legible representation of the large amount of schedule information, as shown in Figure 1. The figure shows time on the horizontal axis and site index on the vertical axis. All crew movements among sites are clearly shown. For example, crew 1 of the second activity will proceed to site 4 once it completes its work on site 1. Clearly, the time


List of sites.

Map of selected sites, showing average productivity data.

Default / Selected Sites

Ref	Site		code
2400	York Maintenance Shop	4	6N 2J1
3002	Blaydon PS	2	3M 2C9
3018	Stanley PS	7	3N 1C2

Arbor Glen PS 55 Freshme...
Toronto M2H 3H6
Traffic: 14,000
Productivity: 1

York Maintenance Shop 40...
Toronto M6N 2J1
Traffic: 4,000
Productivity: 0.5

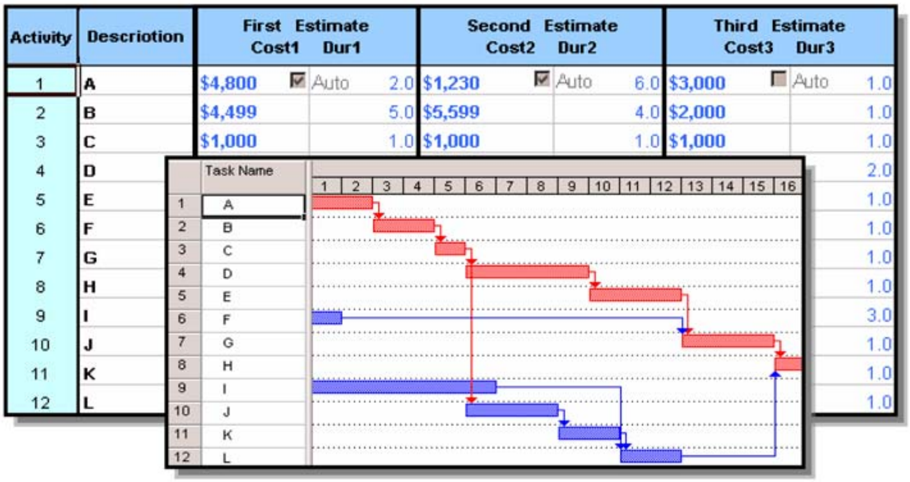
Fig. 2. Site locations and productivity factors.

and cost of moving resources from site 1 to site 4 depends on the distance between the sites and the speed of moving along possible travel routes. As such, the site order (vertical index) becomes an indicator of the sequence of operations and its consequent travel time and cost.

The DSM model is capable of generating schedules by manually changing the options for construction methods, number of crews, the site order, and the amount of interruption at various sites. However, with the large number of possibilities, even for a small network of sites, a cost optimization model becomes necessary to identify the optimum combination of these variables to meet schedule constraints. The optimization model in the DSM involves the setup of the objective function and optimization constraints. The objective function of the model is to minimize total construction cost. Along with proper ranges for the variables, two soft constraints are used: Project duration should be less than or equal to the deadline duration; and total aggregated amount of a given resource is less than or equal to the amount available. To handle the large-scale optimization involved, a non-traditional optimization technique, Genetic Algorithms, has been successfully used in the DSM.

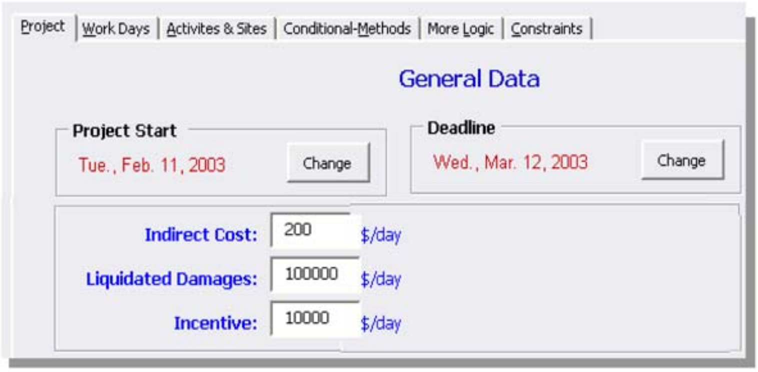
GIS Support

To incorporate GIS features into BAL, a commercial GIS software, Microsoft MapPoint 2002, has been integrated into BAL through visual basic code. The GIS program was utilized to store



Activity	Descriotion	First Estimate Cost1		First Estimate Dur1	Second Estimate Cost2		Second Estimate Dur2	Third Estimate Cost3		Third Estimate Dur3
1	A	$4,800	☑ Auto	2.0	$1,230	☑ Auto	6.0	$3,000	☐ Auto	1.0
2	B	$4,499		5.0	$5,599		4.0	$2,000		1.0
3	C	$1,000		1.0	$1,000		1.0	$1,000		1.0
4	D									2.0
5	E									1.0
6	F									1.0
7	G									1.0
8	H									1.0
9	I									3.0
10	J									1.0
11	K									1.0
12	L									1.0

Fig. 3. Optional estimates and logical relationships.



Project Start: Tue., Feb. 11, 2003

Deadline: Wed., Mar. 12, 2003

Indirect Cost: 200 $/day

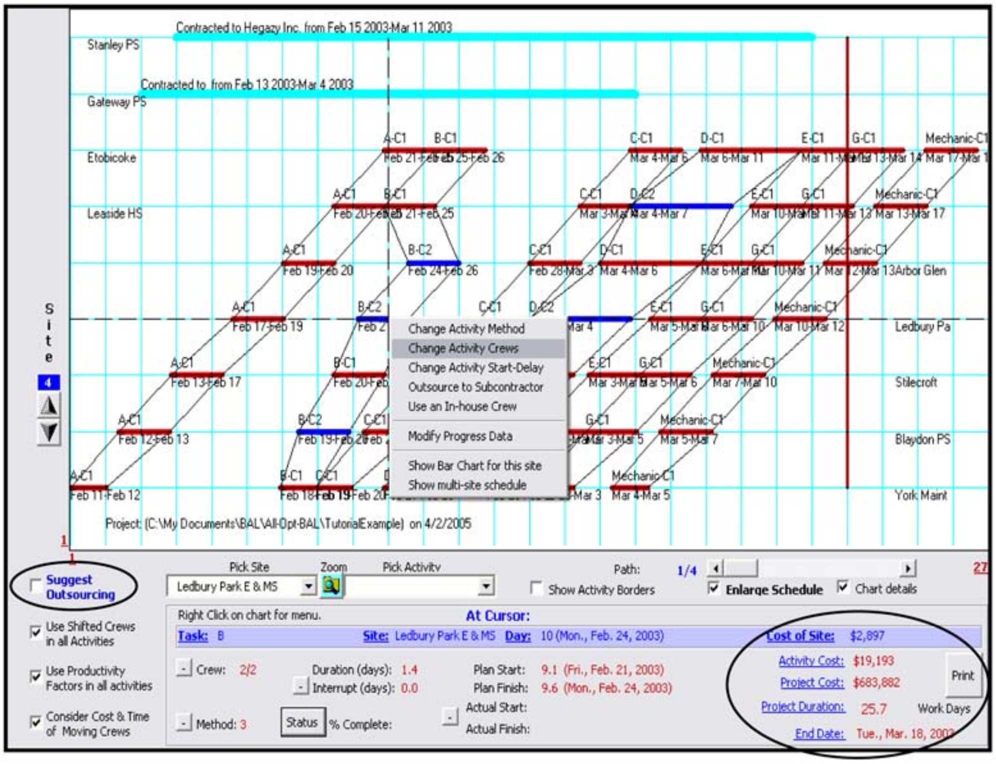
Liquidated Damages: 100000 $/day

Incentive: 10000 $/day

Fig. 4. Main input screen with general data.

sitespecific information, which lends itself well to mapping representation, to facilitate speedy and informed decisions for M&R programs. Site-specific pre-planning information includes location, local weather, land survey data, traffic volume, etc. Using this information, the GIS system automatically calculates the distances from one site to any other, considering the shortest travel routes. Once the distances are calculated, the GIS system then calculates the travel time from each site to any other, considering the speed limits specified for the highways or local roads along a route. These are then directly used to determine the time and cost to transport resources from one site to the other.

During the planning stage, BAL's scheduling engine stores the site-specific data of work quantities, available resources, construction methods, and the time/cost/other constraints. Using this information, the scheduling engine of BAL runs the Genetic Algorithm (GA) procedure and experiments with thousands of random solutions until an optimum is reached. For each random solution, the GA selects the number of crews to use, the site order, and a set of construction methods. In this process, the GIS system feeds the associated distances, moving time, and moving cost, to the scheduling engine. At the end of the GA procedure, an optimum work schedule is determined that respects the time, cost, and resource constraints. Afterwards, another layer of GIS information is generated; containing activities' start and finish dates at the various sites along with the assigned crews. This



Project: (C:\My Documents\BAL\All-Opt-BAL\TutorialExample) on 4/2/2005

☐ **Suggest Outsourcing**

☑ Use Shifted Crews in all Activities

☑ Use Productivity Factors in all activities

☑ Consider Cost & Time of Moving Crews

Pick Site: Ledbury Park E & MS

Pick Activity:

Path: 1/4

☐ Show Activity Borders

☑ **Enlarge Schedule**

☑ Chart details

Right Click on chart for menu.

At Cursor:

Task: B **Site:** Ledbury Park E & MS **Day:** 10 (Mon., Feb. 24, 2003) **Cost of Site:** $2,897

Crew: 2/2

Duration (days): 1.4

Interrupt (days): 0.0

Plan Start: 9.1 (Fri., Feb. 21, 2003)

Plan Finish: 9.6 (Mon., Feb. 24, 2003)

Actual Start:

Actual Finish:

Method: 3

% Complete:

Activity Cost: $19,193

Project Cost: $683,882

Project Duration: 25.7 Work Days

End Date: Tue., Mar. 18, 2003

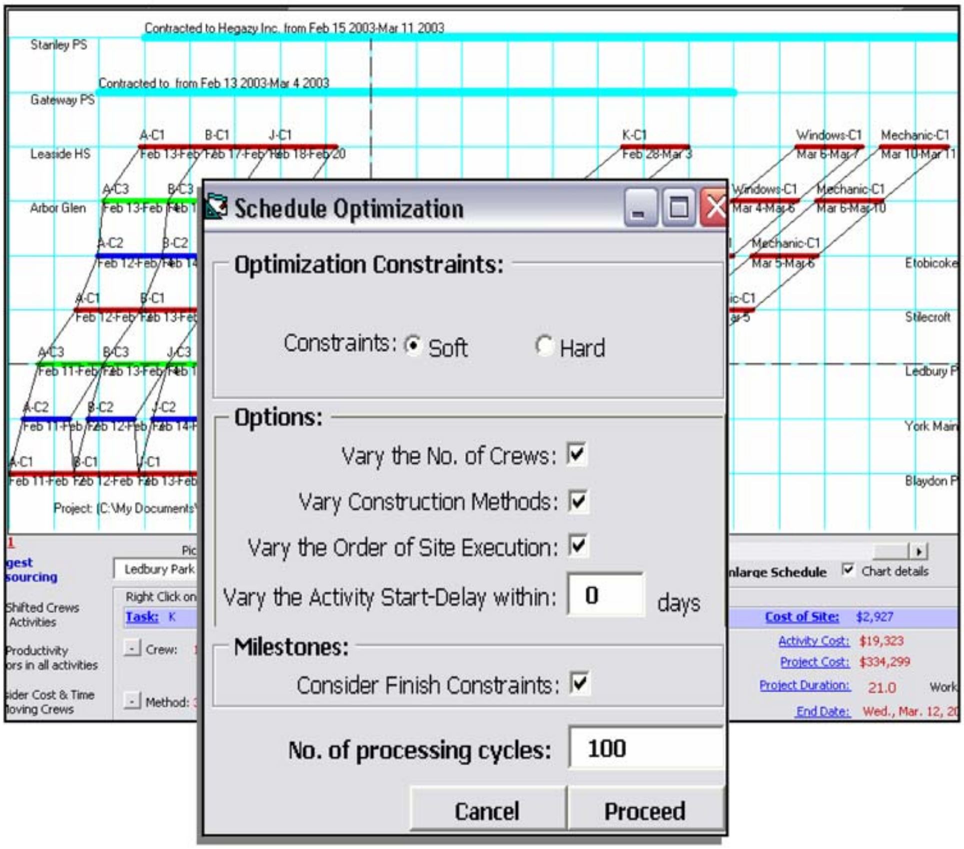
Fig. 5. Initial schedule.

layer of information is then used by a macro written on the GIS system to present the schedule and crew assignments legibly to all project participants.

Example Application

To illustrate the features of BAL and its GIS system, a simple example of an M&R program is presented. The program resembles a school board having a M&R program involving 9 schools. First, the nine schools were selected from a spreadsheet having all school locations at the Greater Toronto Area in Canada (Figure 2). Each school is defined by its address (recognizable by the GIS software). For each site in the list, various pre-planning information was stored, including traffic volume and local productivity factors (monthly values that depend on weather, site access, and other conditions). These productivity factors will be used in the scheduling process to adjust activities' durations, thus, providing realistic execution conditions. As shown in Figure 2, the GIS automatically reads the sites' information and shows a map of their locations and other related information. Various types of data representations are available, such as pie chart, column chart (shown) or sized circles. These data representations provide simple and legible options to compare the values (e.g., productivity factors) at the various sites.

In the present M&R example, 12 activities are involved in each typical site, as shown in Figure 3. The work quantities and three estimates that represent normal, overtime, or weekend work options are shown in the same figure. While the cheaper estimate is the default in generating an initial plan, the other options (faster but more expensive) may be necessary in case durations need to be



Schedule Optimization

Optimization Constraints:

Constraints: ● Soft ○ Hard

Options:

Vary the No. of Crews: ☑

Vary Construction Methods: ☑

Vary the Order of Site Execution: ☑

Vary the Activity Start-Delay within: 0 days

Milestones:

Consider Finish Constraints: ☑

No. of processing cycles: 100

Cost of Site: $2,927

Activity Cost: $19,323

Project Cost: $334,299

Project Duration: 21.0

End Date: Wed., Mar. 12, 20

Fig. 6. Schedule optimization.

shortened to meet a strict deadline. In this case, finding the proper combinations of work options for the activities becomes part of the optimization feature.

Before producing a detailed schedule, the user needs to enter some general data such as start date (February 11, 2003, as shown in Figure 4) and the execution constraints such as deadline (March 12, 2003), incentive ($10,000/day), liquidated damages ($100,000), and any resource limits. As such, this example M&R program has only 22 working days (excluding weekends) to complete the 9 sites.

With the default option being to use in-house crews, the next step was to enter information regarding any special sites that were decided to be outsourced to contractors. In this example, two of the nine sites were pre-specified as outsourced. Once all site-specific information was specified, a detailed execution schedule was generated, as shown in Figure 5.

The initial schedule shows the various color-coded crews. The two contracted sites are shown at the top part of the schedule. It is noted that the initial site order is the one entered by the user in Figure 2. Based on that site order, project duration and cost (considering crew-moving time and cost) were automatically calculated, taking into account the site productivity factors. This resulted in a schedule of 26 days, as opposed to the 22-day deadline. Accordingly, the cost becomes $283,882, plus liquidated damages of $400,000, for a total of $683,882, as shown in Figure 5.

To improve the schedule, it is possible to manually change the crews, work options, and site order to try to meet the deadline and reduce cost (user modifiable options shown in Figure 5). Rather than

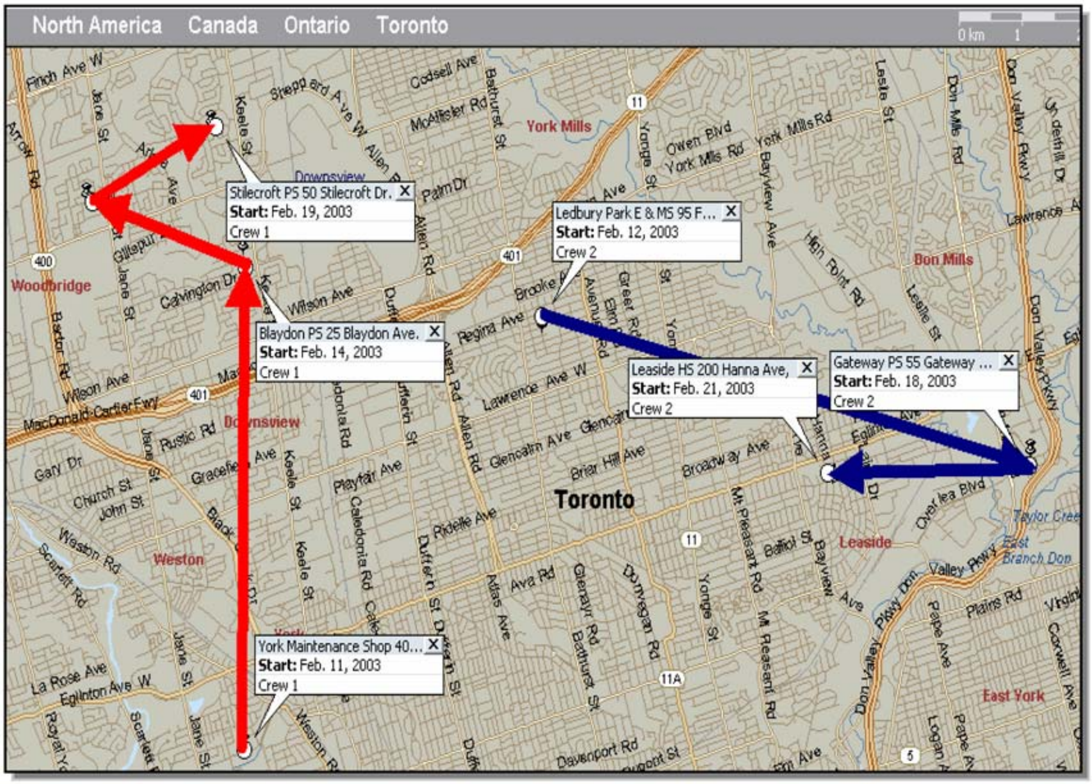


Fig. 7. Crew assignment map.

this manual adjustment process, it is possible to activate the optimization feature, and accordingly, a form for specifying optimization options appears (Figure 6) and allows the user full control over the optimization variables, to suit the project objectives. For this example, various optimization experiments were conducted. The optimum schedule is shown in Figure 6. Project duration of 21 days meets the deadline at a total cost of $334,299.

Once a satisfactory schedule was obtained, site-specific schedule data were automatically exported to the GIS system to provide legible maps of detailed movement of the various crews. An example map generated by the GIS system for the present example is shown in Figure 7. The figure shows two color-coded paths for two crews involved in an activity. The start time for each site is also shown on each site. As such, the map is simple to read and shows when each crew needs to start in which site. An alternative chart that shows detailed travel directions, which can also be generated from the GIS system.

Conclusions

This paper introduced a scheduling model and implementation software, BAL, for optimizing resource allocation in infrastructure projects with multiple-distributed locations. Two unique aspects of the program are discussed in this paper: (1) the powerful scheduling engine that optimizes the execution plan; and (2) the underlying Geographic Information System (GIS).

The GIS system stores and represents various levels of information about the scattered sites involved in a construction/maintenance program. Pre-planning information includes location, productivity factors, land survey data, and traffic volume, etc. Using this information, the GIS system automatically calculates the distances from one site to any other, considering the shortest travel routes. Based on the distances, the GIS system calculates the travel time from each site to any other, considering the speed limits specified for the highways or local roads along a route. These are then directly used to determine the time and cost to transport resources from one site to the other.

During the planning stage, BAL's scheduling engine stores the user-input data of available resources, construction methods, and the time/cost/other constraints. The scheduling engine then runs a Genetic Algorithm to optimize the number of crews to use, the site order, and the set of construction methods. Based on the optimized schedule, another layer of GIS information is generated; containing activities' start and finish dates at the various sites along with the assigned crews. This layer of information is then used to represent the work assignment in a legible manner to the various project participants. One of the outputs is a legible crew assignment map.

An example application was used to illustrate the benefits of using GIS to support schedule computation and better visualization of multiple-site multiple-crew execution plans. The proposed computer program is potentially usable by municipalities and owner/contractor organizations administering a large number of infrastructure assets, such as buildings, highways, and bridges, etc.

Reference

Hegazy, T., Elhakeem, A., and Elbeltagi, E. (2004) Distributed Scheduling Model for Infrastructure Networks. *Journal of Construction Engineering and Management, ASCE*, 130(2), 160–167.