Planning and Scheduling Highway Construction

A. Hassanein[1] and O. Moselhi[2]

Abstract: This paper presents a model designed to integrate the planning and scheduling phases of highway construction projects, focusing primarily on the planning aspects. The model automatically generates the work breakdown structure (WBS) and precedence network respecting job logic and stores a list of construction operations typically encountered in highway projects. The generated network can subsequently be modified to suit the unique requirements of the project being considered. An object-oriented model is developed for planning highway construction operations. The model employs resource-driven scheduling in order to suit the repetitive nature of this class of projects. It accounts for (1) resource availability; (2) multiple preceding and succeeding activities; (3) transverse obstructions; (4) activities with varying quantities of work along the highway length; (5) the impact of inclement weather on crew productivity; and (6) the beneficial effect of the learning curve. At the core of the model is a relational database designed to store available resources and their respective unavailability periods. The model enables both: (1) activities executed by own force; and (2) activities subcontracted out. The model is incorporated in a prototype software that operates in the Microsoft Windows environment and generates schedules in both graphical and tabular formats. An example project is analyzed to demonstrate the features of the developed model.

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Introduction

Repetitive projects can be classified into two broad categories: linear (such as highways and pipelines) and nonlinear (such as high-rise and multiple housing construction) (Vorster et al. 1992). While the former are repetitive due to their geometric layout, the latter are repetitive as crews repeat the same task in all units. The two main differences between these two classes are

1. In nonlinear projects, the unit is a physical entity (e.g., a floor in a high-rise building). Thus, upon completing the work in any unit, crews need to relocate from that unit to the next. This is not the case in linear projects, where, unless a transverse obstruction exists, crews simply progress from one unit to the next along the project length.
2. When adopting multiple crew strategies in a linear project, that project is broken down into sections, each executed by a crew. This is not the case in nonlinear projects, where crews can be assigned to alternating units. For linear projects, assigning crews to nonadjacent units prolongs the construction schedule and increases total cost, as shown in Fig. 1.

The use of network scheduling techniques, such as the critical path method (CPM), in scheduling this class of projects has long been questioned (e.g., Chrzanowski and Johnston 1986). Consequently, techniques tailored to scheduling repetitive projects were developed (e.g., Johnston 1981; Chrzanowski and Johnston 1986; Vorster et al.1992; Harmelink 1995). Unlike network scheduling, these techniques maintain crew work continuity. Models that consider integrating both techniques were developed (e.g., Russell and McGowan 1993; Suhail and Neale 1994; El-Rayes and Moselhi 1998) to schedule nonlinear repetitive projects and are not suitable to scheduling linear ones when multiple crews are employed. Additionally, none of these models consider the planning stage, as they are solely concerned with scheduling activities given a predefined sequence of activities.

This paper presents a flexible model designed to aid highway construction firms in both the planning and scheduling stages. The proposed model assists in the planning phase by automatically generating the work breakdown structure (WBS) and automatically generating the precedence relations among project activities. It also stores templates of precedence networks that define new and rehabilitation highway construction operations

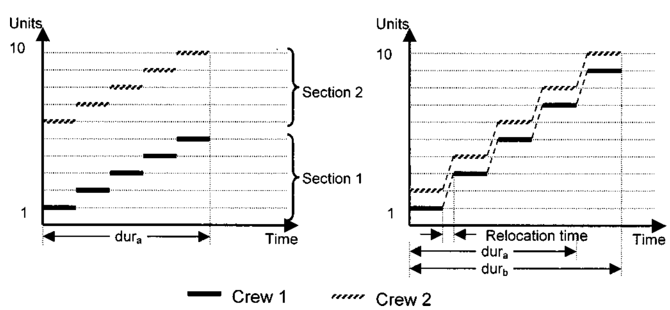

Fig. 1. Crew assignment strategies: (a) assigned to sections; and (b) assigned to alternating units.

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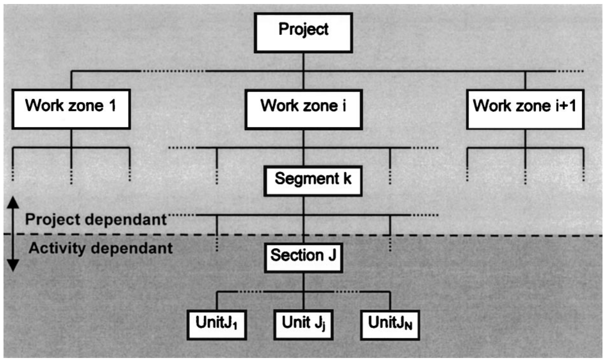

Fig. 2. Work breakdown structure

and can be modified to suit the unique characteristics of each project. The model also stores template precedence networks defining the construction of (1) overpasses; (2) transverse overpasses; and (3) interchanges. A relational database model is developed to store available resources, subcontractors, equipment renting firms, and typical crew compositions. In view of the highly repetitive nature of highway construction, the model utilizes both network and resource-driven scheduling techniques. Utilizing resource-driven scheduling ensures crew work continuity, which maximizes the benefit of the learning curve. To account for the impact of inclement weather, the model considers productivity losses and/or complete work stoppage, depending on the nature of the activity and the severity of weather conditions. The proposed model is implemented in a computer software, providing a friendly graphical user interface and graphical and tabular reporting. A numerical example is presented to demonstrate the features of the proposed model and to highlight its capabilities.

Proposed Model

The effort required to develop a competent plan is perceived as a major obstacle to developing high quality schedules (Chevallier and Russell 2001). This paper primarily focuses on the planning aspects of highway construction projects, accounting for particular constraints associated with this class of projects, such as weather impact on productivity, mobilization and demobilization costs, and the presence of transverse obstructions. The planning process entails

1. Developing the WBS and identifying the various tasks in all project segments; and
2. Generating the precedence network respecting job logic among the identified tasks.

The proposed model is designed to automate the preceding functions, while enabling users to modify built-in settings. This expedites data entry and provides the user with template plans to facilitate the activity definition stage, while providing the required flexibility to define project-specific attributes. The model is flexible enough to enable State Transportation Agencies (STAs) and Departments of Transportation (DOTs) to generate a project's WBS as per their standards. The following sections present how the preceding two functions are addressed in the proposed model. It is worth noting that this paper focuses primarily on the planning stage of flexible pavement construction, and the scheduling algorithm is outside its scope [see Hassanein (2002)].

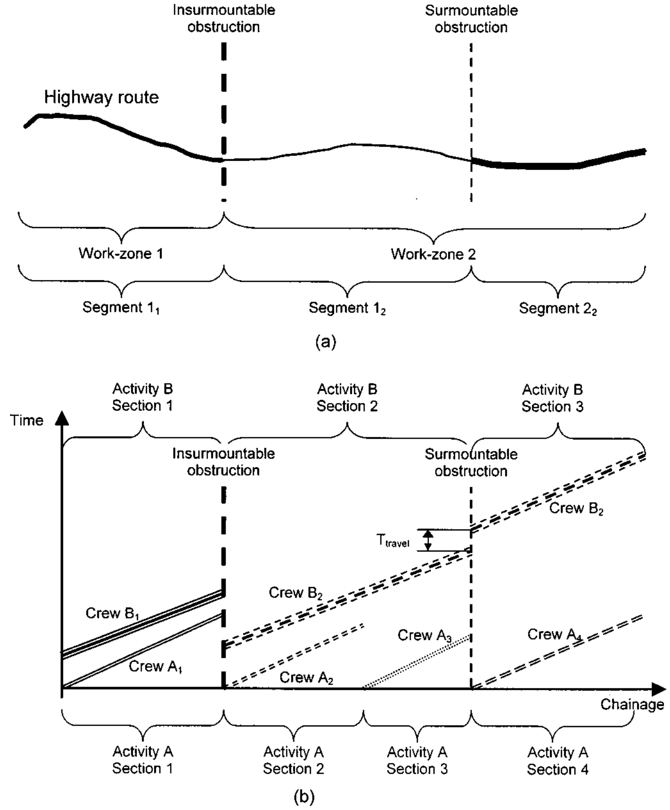

Fig. 3. Project and activity division

Work Breakdown Structure

During the planning and scope definition stage, each activity in a large project is progressively divided into smaller, definable, and trackable units commonly known as work packages. In the proposed model, an activity is divided generically into work zones, segments, sections, and units (Figs. 2 and 3). Transverse obstructions, such as rivers and creeks, play a major role in performing the WBS (Alkass and Harris 1991). There are two types of obstructions: (1) surmountable, where access is granted across the obstruction at an overhead (time and cost); and (2) insurmountable, where no access is granted. Work zones are defined based on the presence of insurmountable obstructions, while segments are defined based on surmountable ones. As for sections, they are mainly defined by the size of the crew formation the number of crews that can work simultaneously on any task).

This is illustrated in the sample project shown in Fig. 3, where two repetitive tasks, "A" and "B," are scheduled. Four crews can work simultaneously on "A," while only two can work simultaneously on "B," as illustrated in the linear schedule shown in part (b) of the figure. It should be noted that the proposed model plots linear schedules in accordance with highway practices, i.e., chainage on the horizontal axis and time on the vertical axis (Vorster et al. 1992; Harmelink 1995). The schedule shows that, while task "A" is divided into four sections, task "B" is divided into three sections. The time required by crew "B_2" to overcome the obstruction, "T_{travel}," is indicated by the loss of time at the location of that obstruction [Fig. 3(b)]. This crossing time depends mainly on the additional travel distance to overcome that obstruction, the road conditions, and the crew size and mobility. It should be noted that, while no resources are shared between work zones, resources could travel between segments within a work zone. Consequently, the size of a crew formation assigned to any repeti-

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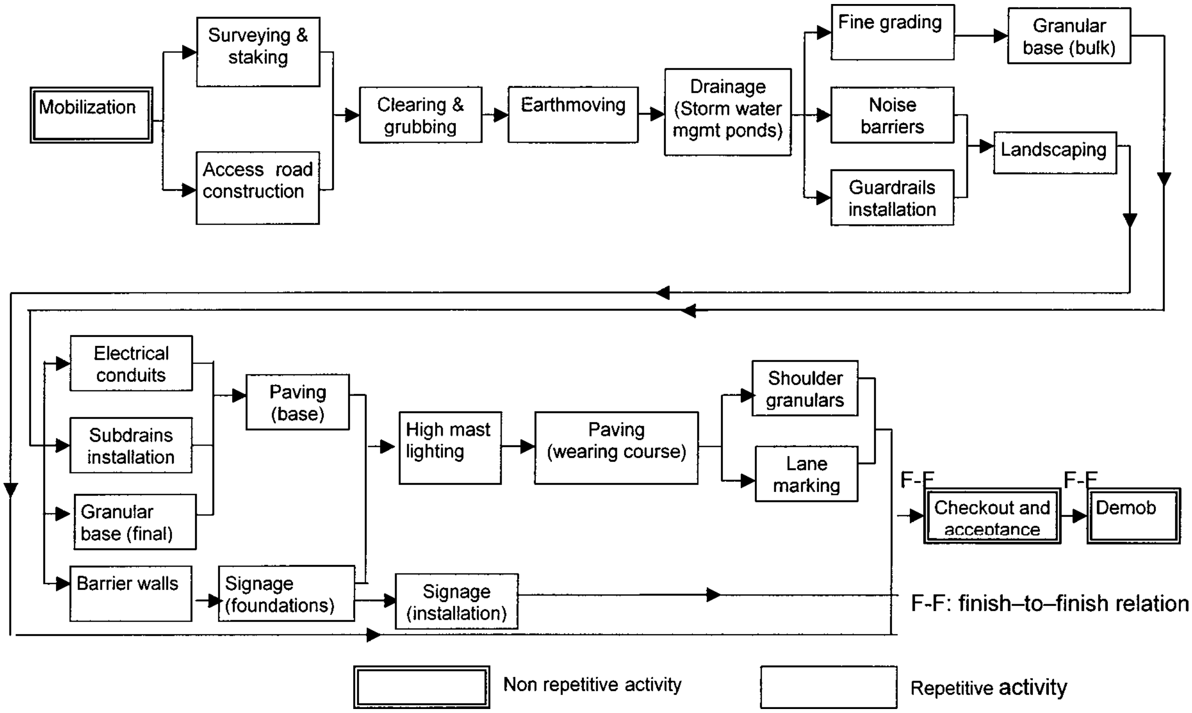

Fig. 4. Precedence diagram for activities on mainline

tive activity must allow for at least one crew to work at each work zone. For example, the minimum size of a crew formation that can be assigned to any repetitive activity in the project shown in Fig. 3 is two (two crews).

The length of a repetitive unit may vary from one activity to another and depends mainly on the nature of work performed. Typically, a unit is considered to be of a certain length (e.g., 500 m in highway construction) along the highway length (Johnston 1981). Previous studies (Harris and Evans 1977) proposed defining the unit length of a repetitive activity based on the minimum buffer required by crews to work without interference from other crews working on preceding or succeeding activities. In the proposed model, project activities are defined utilizing the WBS described previously. Activities in the proposed model are either repetitive (performed once at a specified location) or nonrepetitive (performed throughout the project). A repetitive activity might be repeated in a number of units within a section, segment, and/or work zone, possibly with a different scope of work in each unit.

Tasks commonly encountered in highway construction are clustered into the following categories: (1) clearing; (2) earthmoving; (3) base construction; (4) paving; (5) installations (e.g., utilities); (6) drainage; (7) services (e.g., surveying); and (8) finishing (e.g., sign installation, lane marking). In order to increase the flexibility of the model, an additional category, "other," is added to allow for activities that do not fall within any of the preceding categories, such as foundations and superstructure work for overpasses and culvert installation. These categories aid in defining the susceptibility of each activity to weather as well as setting unit length (minimum buffer) for repetitive activities.

Activity Relationships

The proposed model automatically generates generic precedence networks for both new construction and rehabilitation projects. Rehabilitation projects are considered so as to accommodate the business shift from construction of new highways to rehabilitation of existing ones (NCHRP 1995; Herbsman and Glagola 1998). Lists of activities typically involved in both types of projects and their interrelationships are defined in the proposed model. Selection of any, or all, activities in the list is enabled and the precedence network is generated accordingly. Additional activities, along with their precedence relations, can subsequently be added to the network. Detailed construction of the foundation and superstructure of overpasses is simplified and each element is represented by a single activity, e.g., "overpass construction," and the user is required to provide its cost and duration. In order to determine the activities involved in highway construction projects, and consequently generate the precedence network, pertinent literature was reviewed (e.g., NCHRP 1970; 1995; Oglesby 1982) and interviews were conducted with seven experienced highway personnel. The literature review and interviews were augmented with periodic visits to two highway construction projects: (1) final extension to Highway 407 Express Toll Route (ETR), north of Toronto, Ontario; and (2) construction of a concrete overpass and its approaches to Highway 364 across the Riviére Rouge at Huberdeau, near Arundel, Québec. The former is the first toll highway in Canada and is considered a large project according to the classification proposed by Herbsman (1987). The latter represents a medium-size project according to the same classification (Herbsman 1987).

For new construction, the proposed model generates precedence networks, embracing industry practices to schedule both mainline operations and location-specific operations. Mainline operations are those concerned with the main highway route, such as paving, while location-specific operations are those carried out at a certain location only, such as those associated with constructing a specific overpass. In addition to mainline operations, the proposed model stores precedence networks for (1) overpass con-

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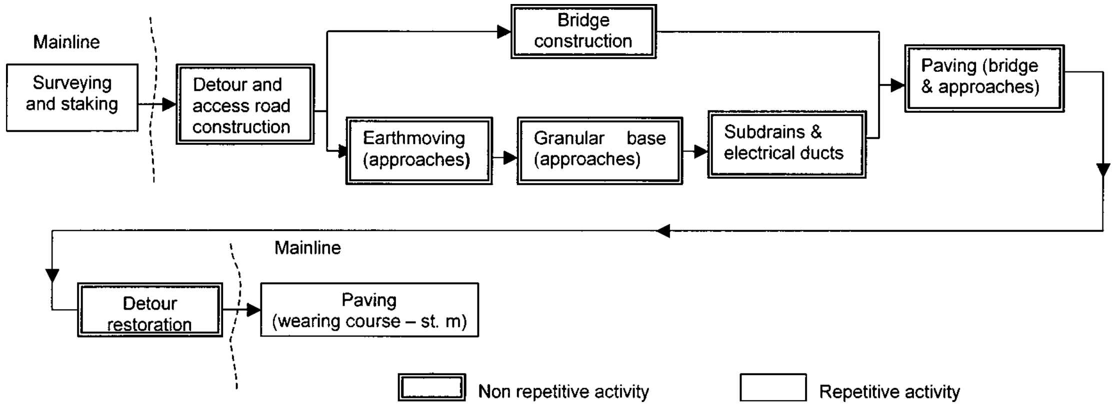

Fig. 5. Precedence diagram for overpass construction at station "m"

struction; (2) transverse overpass construction; and (3) interchange construction. The proposed precedence network for mainline activities is presented in Fig. 4, while Fig. 5 shows the precedence network for overpass construction at station "m." It should be noted that the precedence network shown in Fig. 4 represents the sequence of operations at a location along the highway. Unless otherwise specified, all relations are finish-to-start, with no lag time.

For rehabilitation of existing highways, the proposed model accounts for the three most common types of highway rehabilitation processes (NCHRP 1997), which are (1) pavement overlay projects; (2) pavement replacement; and (3) adding new lanes to highways. Activities considered for overlay projects are (in order of precedence): (1) applying overlay; and (2) lane marking. For replacement projects, the following activities are considered (in order of precedence): (1) stripping existing pavement; (2) subgrade stabilization; (3) applying seal coat; (4) paving; and (5) lane marking. The activities involved in widening an existing highway, in order of precedence, are: (1) widening and compacting embankment; (2) constructing drainage layers; (3) base construction; (4) paving; and (5) lane marking. All these activities have finish-to-start relations with predecessors and/or successors, with no lag time.

Object-Oriented Representation

Object-oriented modeling (Rumbaugh et al. 1991) is utilized to represent various project entities. Objects with common attributes and behavior are grouped into a class, resulting in a concise and efficient representation of project entities. The proposed object model makes use of abstraction, data encapsulation, and inheritance concepts to develop an efficient and organized hierarchy of classes. It builds upon the model developed by El-Rayes and Moselhi (1998) and tailors it to highway construction, and it is schematically illustrated in Fig. 6. All objects from the earlier study were modified to take full advantage of encapsulation and polymorphism. Objects with double borders were added to represent objects developed in this study to tailor the earlier object model to highway construction. This design imposes no restrictions on the number of (1) preceding or succeeding activities; (2) crews that can be assigned to an activity; or (3) availability periods for each crew. A project is viewed as an object composed of a group of activity objects, interconnected to satisfy the job logic, and stores data such as project title, start date, and work calendar. Activity objects, on the other hand, store data such as activity name, its category, its predecessor(s) and successor(s), and the number of potential crew formation objects. In turn, an activity is viewed as an object to which a group of one or more crew formation objects could be assigned. A crew formation object stores data such as number of crews that can work concurrently and is a combination of one or more crews that can be assigned concurrently to an activity. A crew object stores data such as crew daily productivity, cost, and mobility data, and it is represented by a series of objects, each representing an individual resource (i.e., equipment or labor). "Subcontractor" objects replace "crew formation" objects for activities not executed by one's own force and store data related to possible productivity rates and associated unit cost. This data can be determined through (1) consultation with known subcontractors; (2) historical records; or (3) industry averages. "Obstruction" objects can be defined for a project to model transverse obstructions.

In addition to introducing new objects to represent highway construction operations, certain modifications in the interobject relations were deemed necessary. For example, "crew formation" objects were only defined for repetitive activities (El-Rayes and Moselhi 1998). In the proposed model, crew formations are defined for an "activity" object, enabling its inheritance by both subclasses (i. e., repetitive and nonrepetitive activity objects). This enables full integration of nonrepetitive activities into the scheduling process.

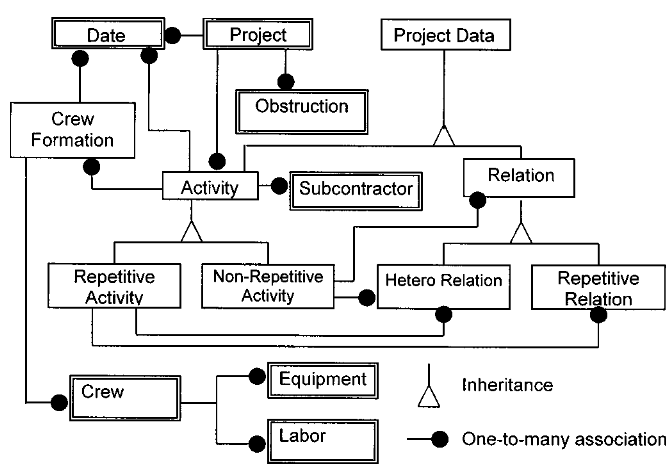

Fig. 6. Developed object-oriented model [modified after El-Rayes and Moselhi (1998)]

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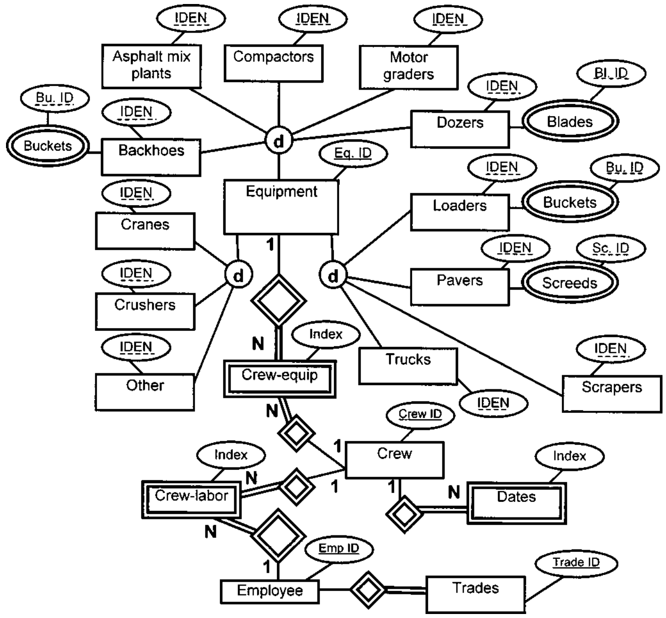

Fig. 7. Developed entity-relation diagram

Database

At the core of the proposed model are three relational databases. The first stores daily precipitation, temperature, and wind speed for three periods (morning, afternoon, and overnight) for each day in the locality of the project. The second stores swell and shrinkage values for various soil types. The third is a relational model that stores data related to the contractor's resource pool. This includes (1) owned equipment; (2) labor force; (3) equipment rental firms and (4) subcontractors. The developed entity relation diagram (ER diagram) for the resource database is shown in Fig. 7. Equipment types regularly employed in the construction of this class of projects are stored in the database. These are (1) asphalt mix plants; (2) backhoes; (3) compactors; (4) cranes; (5) crushers; (6) dozers; (7) loaders; (8) motor graders; (9) pavers; (10) scrapers; and (11) trucks. Attributes stored in the database pertaining to each equipment type are in accordance with their respective manufacturers (e.g., Caterpillar 1997) and are listed in the Appendix.

As shown in Fig. 7, equipment attachments, such as blades for dozers and screeds for backhoes and pavers, are considered independent resources and are treated as such. The database also stores a list of assignment dates for all pieces of equipment and labor. This enables determining whether any piece of equipment, along with all its peripherals, would be available within any specified period. Each time the database is queried for availability status of a resource within a certain time period, it compares that time period to all periods in which that resource is engaged. If no overlap exists, the resource is declared available and is then assigned to the crew. Otherwise, similar resources are investigated to determine whether any are available during that period. If none are available and renting additional equipment is considered, then the database is employed to replace the scarce resource with one from the defined rental pool. In addition, the database plays a key role in ensuring efficient resource utilization; when selecting equipment, the available resources are ranked in an ascending order of their respective total hours worked. This allows for uniform distribution of work amongst similar pieces of equipment.

Scheduling Algorithm

A flexible model employing resource-driven and traditional network scheduling techniques has been developed. The developed model utilizes dynamic programming in generating optimized schedules based on project total cost, duration, or their combined impact for what is known as "cost-plus-time" or "A+B" bidding (Herbsman and Glagola 1998). The model is an extension to that developed earlier by El-Rayes and Moselhi (1998) and introduces additional features tailored primarily for highway construction. The algorithm has been discussed elsewhere (Hassanein 2002). The proposed model imposes no limit on the number of preceding or succeeding activities. Maintaining crew work continuity has been recommended to minimize work disruptions and associated costs. This is particularly true for highway construction projects, because the equipment used in this class of projects are typically heavy and expensive, and their idle time is costly (Vorster and De La Garza 1990). Accordingly work interruptions are not permitted in the proposed model. The scheduling algorithm expands upon that proposed earlier by El-Rayes and Moselhi (1998) and tailors it to highway construction by (1) dividing repetitive activities into sections, each assigned to a crew; (2) accounting for the impact of transverse obstructions; (3) enabling the definition of subcontracted activities; and (4) forming crews on a "just in time"–like manner from available resources at its scheduled time.

Highway construction operations are particularly susceptible to inclement weather (NCHRP 1978; El-Rayes and Moselhi 2001). The degree to which an activity is impacted by inclement weather depends on the nature of that activity and on the severity of the weather conditions. Inclement weather can result in significant productivity losses and can eventually halt operations altogether (El-Rayes and Moselhi 2001), either for safety or quality concerns. The proposed model considers the impact of (1) pre-

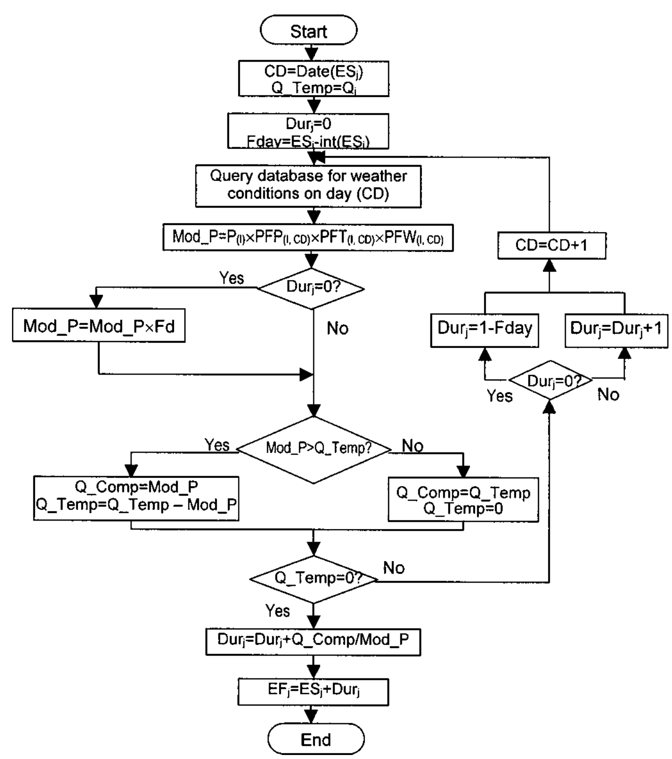

Fig. 8. Proposed algorithm to account for weather impact on activity duration [adopted from El–Rayes and Moselhi (2001)]

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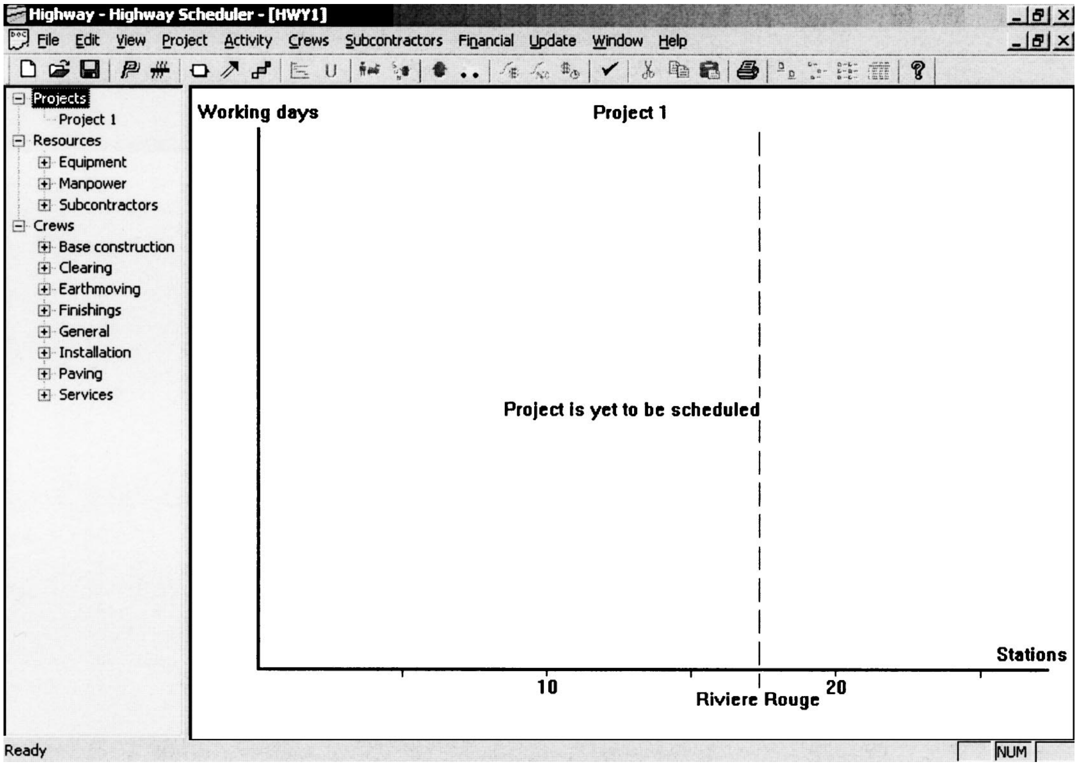

Fig. 9. Main software screen

cipitation; (2) temperature; and (3) wind speed on crew productivity. The daily productivity, "$P_{c/D}$," of crew "c" on day "D" is revised based on the expected weather conditions at the corresponding calendar day "CD," as stored in the database, and the type of operations performed. The findings of the aforementioned study (El-Rayes and Moselhi 2001) are incorporated in the proposed model to account for the impact of precipitation on (1) earthmoving; (2) base construction; (3) construction of drainage layers; and (4) paving operations. In addition to considering the impact of precipitation on crew productivity, as does the model of El-Rayes and Moselhi (2001), the proposed model accounts for losses in productivity caused by wind speeds and temperature. The model is flexible and allows the user to change the default values and specify the susceptibility of each activity to each of the weather conditions. Fig. 8 shows the algorithm employed to account for the impact of weather on the duration of activity "i" in unit "j." The algorithm commences by determining the calendar date, "CD," corresponding to the actual start date of work on unit "j," "ES_j". As the work on that unit progresses, "C_Temp" updates and stores the remaining quantity of work to completion of that unit. The duration of works on unit "j," "Dur_j," is initialized to zero (0). The start date of an activity can contain a fraction, "Fday," indicating that works can only commence after a certain hour of the day. The weather database is queried to determine the expected conditions on the day of interest, and adjustment factors for activity "i" due to precipitation "PFP_i," temperature "PFT_i," and wind speed "PFW_i" are determined. The quantity of work completed during that workday, "Q_Comp," is computed and deducted from the remaining quantity of work ($C\_Temp' = C\_Temp - Q\_Comp$). The preceding procedure is repeated until "C_Temp" is less than, or equal to, "Q_Comp," signifying that work in the unit is completed on that day. The completion date of works on unit "j," "EF_j," determined from

$$EF_j = ES_j + Dur_j \tag{1}$$

Computer Implementation

The proposed model is incorporated in a prototype software, operating in the Microsoft Windows environment. The software is coded in Visual C++, utilizing object-oriented programming and Microsoft Foundation Classes (MFC). Microsoft Access is employed as the database management system (DBMS). The software provides a user-friendly interface utilizing menus, multiple windows, and dialog boxes to facilitate data entry. Fig. 9 shows the main window of the developed prototype, while Figs. 10 and 11 show the dialog boxes designed to acquire the list of activities for the project at hand and activity data, respectively. In an effort to facilitate the use and implementation of the generated schedules, the system (1) generates linear schedules in the format adopted in highway construction, where the vertical and horizontal axes represent time and chainage, respectively (Harmlink 1995); (2) assigns a unique color to each activity in order to enhance visualization; (3) generates the usual bar charts (Gantt charts), compatible with the linear schedule produced by the system; and (4) provides the flexibility to generate bar charts at two levels of detail, namely, at the activity level and at that of each individual crew. The developed software has a number of interesting features: (1) it contains a fully-integrated relational database storing own resources and typical crew compositions; (2) it enables the user to specify holidays and designated work weeks; (3) it accepts several input file formats (Microsoft Excel and tab-delimited text files); (4) it provides a simple, user-friendly graphical user interface, facilitating data entry and retrieval; (5) it generates graphical and tabular reports at different levels of detail to

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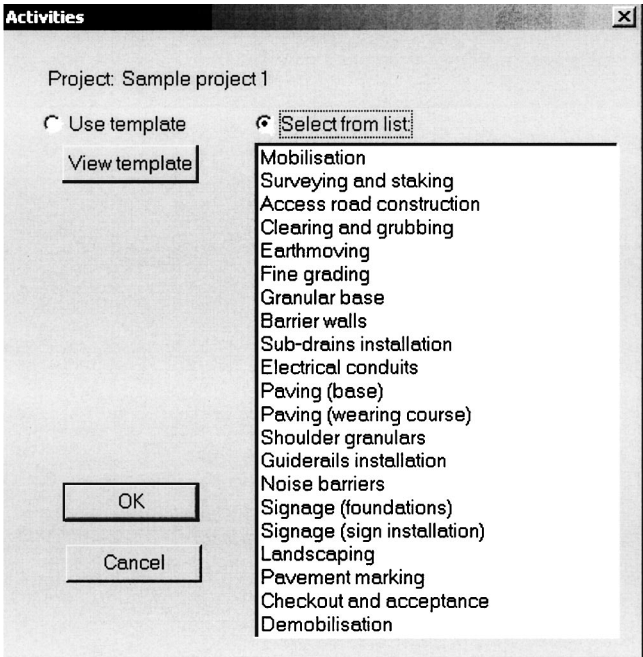

Fig. 10. Dialog box for selecting project activities

satisfy all levels of the construction team; and (6) it facilitates updates and revisions pertaining to activities and crews.

Application Example

In order to illustrate the use of the proposed model and demonstrate its capabilities, it is used to plan the mainline activities of a portion of the 407 Express Toll Route (ETR) north of Toronto, Ontario, Canada [Fig. 12 ("Lavalin" 2002)] following the planning procedure described earlier. The highway has a total length of 108 km and was completed in two phases—the first extending from Highway 410 in Brampton to Highway 404 in Markham, the second composed of two sections: the East extension from Highway 404 to Highway 7, and the West extension from Queen Elizabeth Way (QEW) to Highway 410. Phase 1 was open to the public on June 7, 1997, and the project was completed in August 2001. As can be seen from the preceding discussion, project phases were defined at locations of two major arteries. This was done in order to provide an alternate link between highways 410 and 404 and to alleviate the pressure on existing highways.

Each of the two extensions of Phase 2 was further subdivided into work zones, in order to divide the work into smaller, more manageable contracts. This division was carried out in a manner that divides the scope of work equally among zones. The West extension was divided into three separate work zones (W1, W2, and W3), each administered independently. The boundaries separating work zones were defined at the locations of transverse obstructions. In the West extension, Bronte Creek separated zones W1 and W2, while the 16-Mile Creek separated zones W2 and W3. On the other hand, the East extension, which encompassed considerably less work than the West extension, was divided into two work zones (E1 and E2). The boundary separating zones E1 and E2 was defined at the location of the West Duffins Creek. Multiple crew strategies were adopted in several contracts to meet the completion deadline and were assigned to sections rather than alternating units, as per the procedure adopted in the proposed model. This hierarchical division of Phase 2 of the 407-ETR is in line with the WBS of the proposed model. For example, the West extension is defined as a highway intercepted by two insurmountable obstructions (the Bronte and 16 Mile Creeks) and ten surmountable ones (e.g., Highway 5).

The mainline activities for work zone W1 of the West extension are aggregated and simplified in the form of a bar chart as shown in Fig. 13. This was done in order to bring them to the same level of detail as the activity definition in the proposed model. Precedence relations (inferred from the activities' relative start and finish times) are superimposed on the figure to show activity interdependency. The figure shows that the precedence relations defined in the model map well against those employed in developing the schedule for the activities of W1. It should be noted that, due to its design as an all-electronic, open access toll highway, construction included the installation of an intense network of electrical and monitoring devices. While these activities are not included in the predefined activity list, they could readily be incorporated into the generated schedule upon defining their precedence relations. In addition to the preceding activities, the scope of work in the West extension included the construction of six overpasses, five transverse overpasses (underpasses), and six interchanges. The activity lists and their interrelations detailing the construction of these location-specific projects are predefined in the proposed model. All that remains is selecting crews from the database and the project is ready for scheduling.

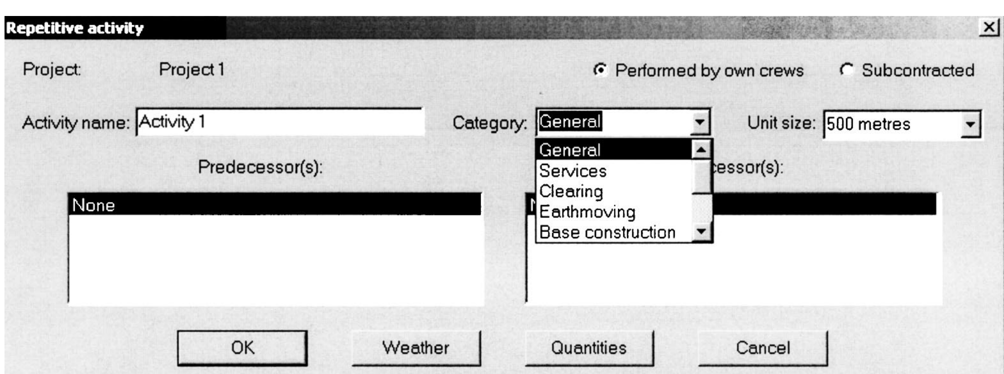

Fig. 11. Dialog box for entering activity data

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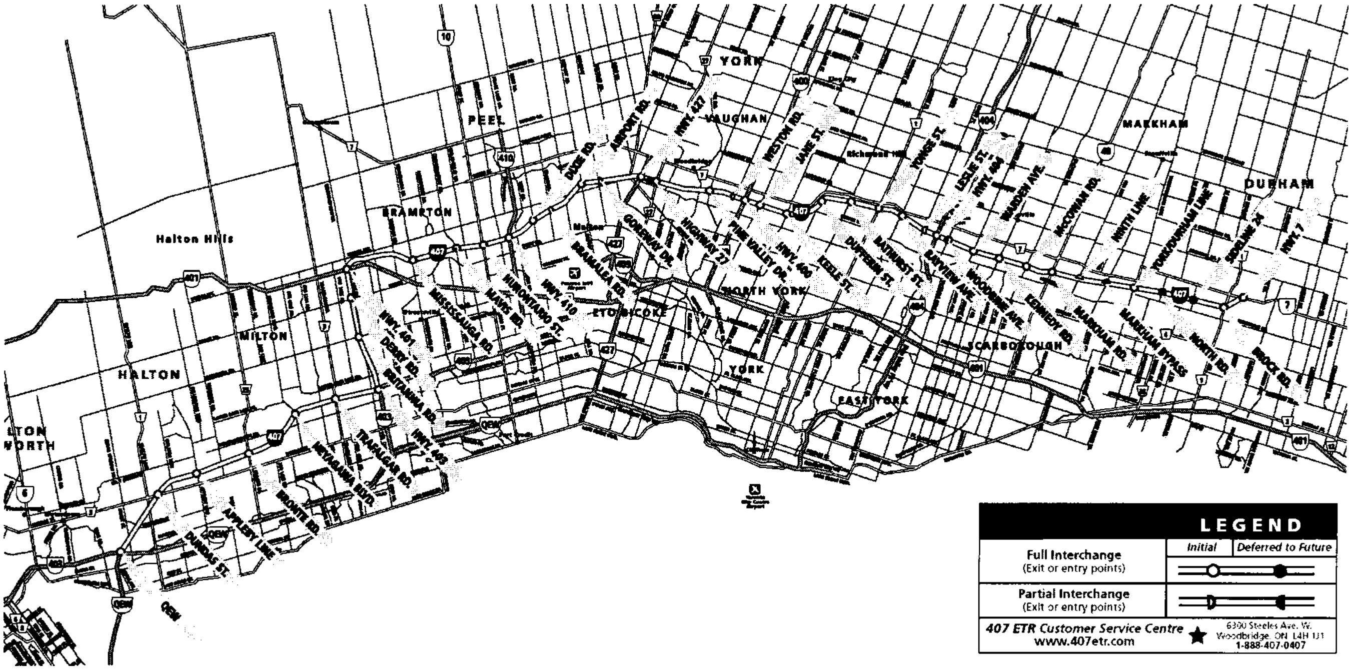

Fig. 12. Map of 407 Express Toll Route (ETR) ("Lavalin" 2002)

Summary and Concluding Remarks

An object-oriented model was presented to plan and schedule highway operations. The model divides highway projects into work zones and segments, generates the WBS, and automatically develops the precedence network respecting job logic. The generated precedence network can subsequently be modified to suit the particular characteristics of each project. The model employs resource-driven scheduling and accounts for the impact of transverse obstructions on the planning and scheduling phases. The model also accounts for the impact of inclement weather on crew productivity and considers the beneficial effect of the learning curve. At its core is a relational database designed to facilitate the allocation of resources to activities in progress. The database stores available resources and their unavailability periods, as well as crews typically employed in various operations. The model enables both executing activities through employing one's own force and subcontracting activities to specialized contractors. It is incorporated in a prototype software that operates in the Windows environment and generates schedules in both graphical and tabular formats. An example project is analyzed to demonstrate the features of the developed model and to illustrate its applicability to planning highway construction operations.

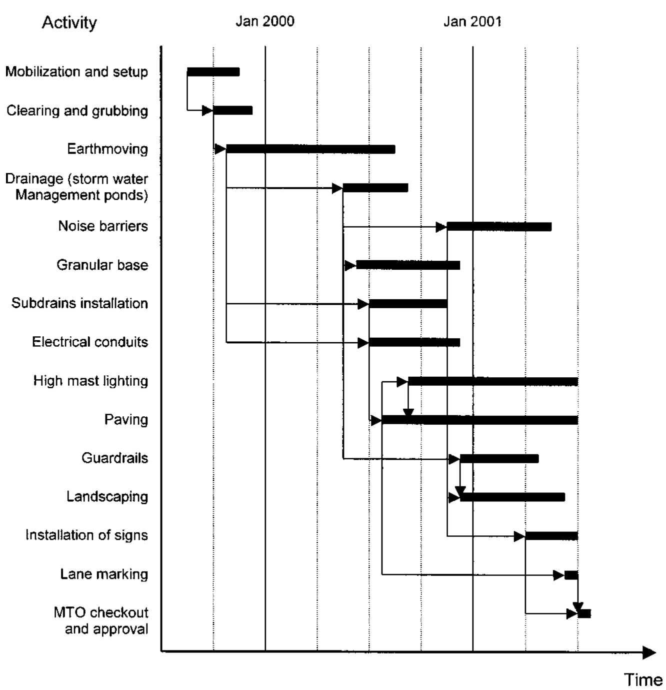

Fig. 13. Simplified bar chart for mainline activities of segment W1

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Appendix. Equipment Data Stored in Database

The following data is stored for all equipment types:

- Equipment identifier: a unique identifier for each piece of equipment (e.g., 50101)
- Equipment: an identifier for each equipment model (e.g., 2101)
- Hours worked: total number of hours worked by equipment (e.g., 200 hs)
- Table 1 lists the attributes stored for each equipment type

J. Constr. Eng. Manage., 2004, 130(5): 638-646

Table 1. Attributes Stored for Each Equipment Type

Equipment	Attribute stored	Units
Asphalt mix plants[a]	Mobility (yes/no)	—
	Daily productivity	ton/h
	Capacity	tons
	Assembly cost	$
Backhoes[b]	Flywheel power	hp
	Maximum digging depth	m
	Breakout force	kN
Compactors	Type (vibrating/sheepsfoot/pneumatic)	—
	Material (soil/asphalt)	—
	Operating weight	tons
	Flywheel power	hp
	Speeds (1/2)	—
Cranes	Daily productivity	tons
	Maximum lifting weight	tons
Crushers	Daily productivity	tons
	Capacity	m^3
Dozers[c]	Mounting (track/wheel)	—
	Flywheel power	hp
	Operating weight	tons
	Ground contact area	m^2
Loaders	Mounting(track/wheel)	—
	Flywheel power	hp
	Cycle time	s
	Maximum travel speed	km/h
Motor graders	Flywheel power (shifts 1–3)	hp
	Flywheel power (shifts 4–8)	hp
	Operating weight	tons
	Travel speed (forward)	km/h
	Travel speed (reverse)	km/h
Pavers	Flywheel power	hp
	Mounting (track/wheel)	—
	Paving speed	m/min
	Travel speed	km/h
	Maximum theoretical capacity	ton/h
	Hopper capacity	m^3
Scrapers	Type (standard/push-pull/elevating)	—
	Struck capacity	m^3
	Heaped capacity	m^3
	Flywheel power (tractor)	hp
	Flywheel power (scraper)	hp
	Rated load	kg
	Top speed (loaded)	km/h
	Width of cut	m
	Maximum depth of cut	m
	maximum depth of spread	m
Trucks	Type (water/haul/off-highway)	—
	Flywheel power	hp
	Gross power	hp
	Operating weight	kg
	Maximum gross weight	kg
	Top speed loaded	km/h
	Maximum capacity	m^3
	Struck capacity	m^3
	Heaped capacity	m^3

[a]Linked to screeds table (storing screed widths).

[b]Linked to buckets table (storing bucket capacities).

[c]Linked to blades table (storing blade widths and heights).

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J. Constr. Eng. Manage., 2004, 130(5): 638-646

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