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DSS for Estimating and Scheduling of Highway Projects (HWSDSS) with Optimization

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☐ ABSTRACT ☐

This paper presents HWSDSS the Decision Support System for estimating and scheduling of highway construction projects. HWSDSS integrates the estimating process (calculating the quantity of work for project activities) and the scheduling optimization process. HWSDSS performs the quantity take-off for each activity in each repeated segment based on the ground topography data and the designed cross-sections of the highway. HWSDSS utilize the mixed combinatorial-dynamic programming technique to generate the optimum schedule that corresponding to the planner target (minimum duration, or minimum cost).

Keywords: DSS, Estimating, Scheduling, Highway, Road.

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نظام دعم قرار لتقدير الكميات والجدولة الزمنية المثلى لمشروعات الطرق الرئيسية (HWSDSS)

الدكتور هاني نجا *

(تاريخ الإيداع 31 / 10 / 2009. قُبِل للنشر في 2009/12/16)

□ ملخّص □

تقدم هذه الورقة البحثية نظام دعم القرار HWSDSS لتقدير كميات الأعمال والجدولة الزمنية لمشروعات الطرق. النظام بشكل متكامل يقوم بحساب كميات أعمال أنشطة المشروع وإجراءات الجدولة الزمنية المثلى لأنشطة المشروع. يتم حساب كميات الأعمال لكل نشاط في كل قطاع من الطريق بالاعتماد على شكل الأرض الطبيعية والمقطع العرضي التصميمي للطريق. يعتمد النظام على تقنية الجدولة الزمنية " التوافيق–البرمجة الديناميكية المختلطة " لتوليد الجدولة الزمنية المثلى طبقاً لهدف المستخدم (أقل زمن للمشروع أو أقل كلفة للمشروع).

الكلمات المفتاحية: نظام دعم قرار، تقدير كميات، جدولة زمنية، طرق.

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Introduction:

Highway projects have special characteristics because of their linear nature. 1) They are composed of a large number of horizontal segments, so the work spread over a large area. 2) Most of these segments are of a repetitive modular nature. 3) The sequence of activities is not discrete. Rather, the activities progress continuously in sequence along the length of the project. 4) The equipment requirements are enormous and thus emphasis must be placed on maximization of equipments utilization.

Application of procedure to improve planning, scheduling, and control of highway construction and maintenance projects can provide many benefits. Improved organization of the construction process usually reduces overall cost, increases construction safety, and shortens the project duration. For new highway construction, a shorter duration increases public safety by allowing a needed highway to open earlier. For highway maintenance projects, a shorter duration also increases public safety by reducing traffic interruption and detour.

Problem Statement:

In the literature several methods have been proposed for scheduling linear construction projects, such as LSM (Linear Scheduling Method) proposed by (Johnson, 1981) and (Harmelink and Rowings, 1998), RSM (Repetitive Scheduling Method) proposed by (Harris and Ioannou, 1998). In Addition, several techniques have been developed for linear or repetitive project scheduling optimization. Technique, such as linear programming (Reda, 1990), Dynamic programming (Selinger, 1980) and (Moselhi and El-Rayes, 1993), mixed combinatorial-dynamic programming (Naja, 2001). If the full benefits of a scheduling method are to be realized, the methods must be applied to the appropriate situation. In general, construction projects have major dominant characteristics, operations, or resources whose planning affect or dominate planning of other operations and resources. Managers focus their first attention on such dominant features. For example, Cut and Fill operation is one of the most important, difficult, time and resources consuming task in most highway projects. A major focus should be on selection of equipments for the Cut and Filling work. The choice of Cut and Filling equipments should logically depend primarily on the type of soil, the natural ground topology under the highway line, and the highway geometry design.

It should be recognized that most of the linear scheduling techniques assume that each repetitive activity performed consecutively by the same crew. But this assumption does not always meet the real highway project situation, because in some highway construction project (with a limited project duration) the manager enforces to hire more than one crew to work simultaneously in different locations or zones for a given repetitive activity such as cut & fill activity to reduce the project duration. Moreover, in some cases the embankment soil in backfill zone can be obtained from the resulting excavation soil in excavation zone.

In addition, most of the linear projects scheduling techniques are designed to maintain the work continuity for the repetitive activities. The continuous work constraints were presented in the following form: the start date of a repetitive activity in a given repetitive unit depends on the finish date of the same repetitive activity in the previous repetitive unit; this formula is written as the following.

$$S_i^j = F_i^{j-1} \qquad j = 1,2,\dots m_i \qquad (1)$$

Where:

S_i^j :The scheduled start date of the repetitive activity i in unit or segment j .

F_i^{j-1}: The scheduled finish date of the repetitive activity i in unit or segment $j-1$.

m_i : Number of repetitive unit or segment for the repetitive activity i .

But this work continuous constraints formula not always represent the real project situation, especially in highway construction projects, for example, Filling operation is usually distributed and compacted into uniform layers not more than 25 cm. These layers may span over more than one segment. Figure (1) illustrated the layers construction sequence in a backfill zone.

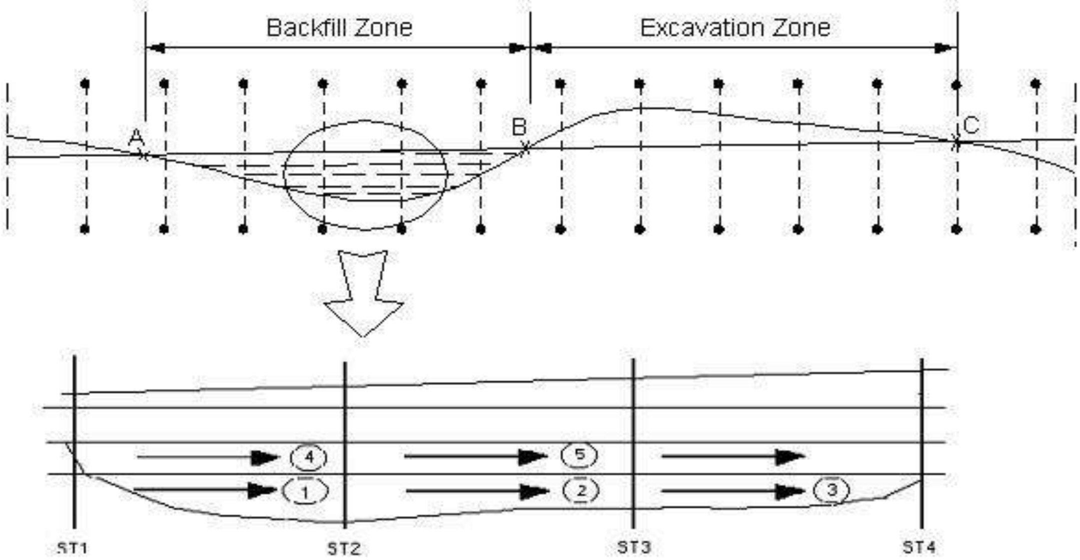


Figure (1) Layers construction sequences in a backfill zone.

The continuous work constraints formula (1) does not represent the above situation. So, it is required to schedule the filling activity in the backfill zone by a way that simulates the real sequence of the layers construction as illustrated in Figure (2).

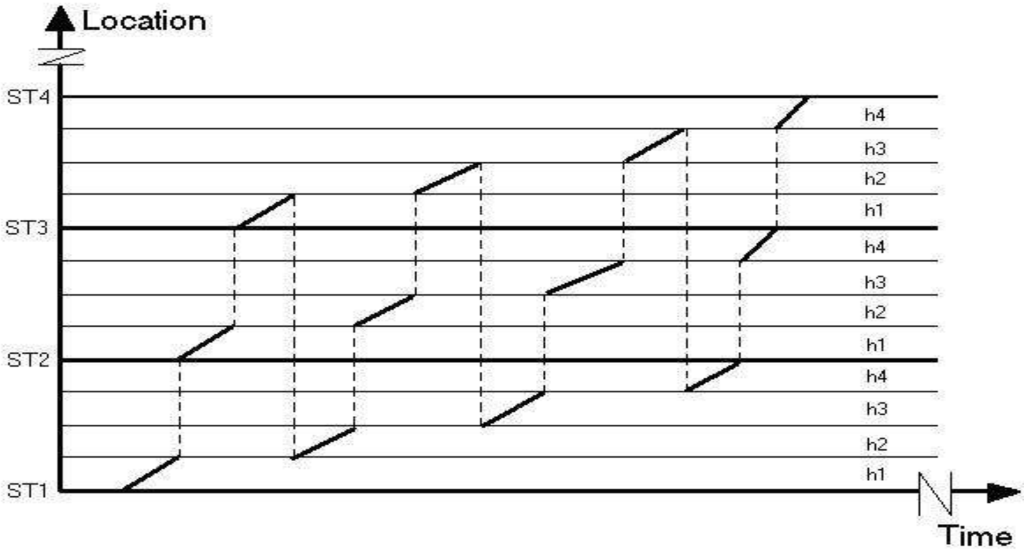


Figure (2) scheduling the Cut and Fill activity in backfill zone.

As shown in Figure (2) within a given backfill zone, each layer should be distributed and compacted along the zone segments before the start of the next layer.

Research Objectives:

This paper presents a proposed Decision Support System (DSS) for estimating and scheduling the construction of highway projects (HWSDSS). In order to schedule the highway projects to meet the situations that has mentioned in the problem statement, the construction planning functions performed by HWSDSS include the following:

- Enumeration of tasks required for construction of a given highway project.
- Generate cross-section for each station based on the ground geometry.
- Estimate quantity of work that required for each activity based on the ground topology and the highway geometric design information supplied by the user.
- Allocation of resources for tasks.
- Determination of tasks time and cost.

The planning is guided by economic and managerial consideration, such as least cost and fast completion.

HWSDSS Structure:

As shown in Figure (3) the proposed Decision Support System has the following four main components:

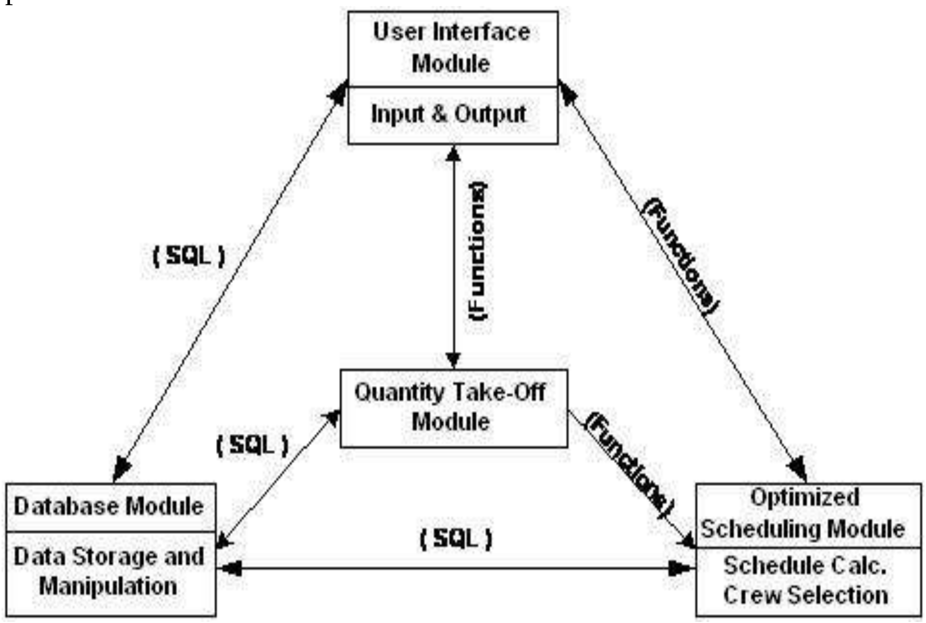


Figure (3) Structure of the HWSDSS.

1- Relational Database module 2- Activity quantity take-off module
3- Optimum Schedule generator module 4- User interface module

The four components are linked in a way that the process of information transmission is fully automated, this done by using structure query language (SQL) and special designed functions such as the function that used to manipulate the data entered by user.

Relational Database Module:

HWSDSS use the database to store all the required data about the system objects or entities during the quantity take-off and scheduling process. The system database has been designed through three stages, Requirement definitions, conceptual design, and implementation design.

1) Requirement definitions are user information requirements and the processing requirements, which were compiled by interviewing several expert project managers. The experts were requested to comment and emphasize on the special difficulties and special requirement encountered during the construction scheduling of highway projects. The output of requirement definition is a formal set of entities or objects and its required attributes and its relationships.

2) Conceptual Design, which is the process of constructing a detailed architecture for a database that is independent of implementation details. This done by consolidation all the entities, relationships and its attributes in an integrated entity-relationship (E-R) diagram as shown in Figure (4).

3) Implementation design, the E-R diagram must be transformed to a relational model before it can be implemented. In the relational model objects or entities are viewed as two-dimensional tables, which are related together and represent the overall needed data elements or attributes. HWSDSS relational model has implemented using Microsoft Access database management system.

Activity Quantity Take-off Module:

This module includes routines and functions for calculating the quantity of work to be accomplished for each repetitive activity in each repetitive segment (area between two successive stations). HWSDSS uses the following four types of objects to perform the quantity take-off for highway project activities.

1) ***Cross Section***: this defines the surface shape of the highway at different locations.

2) ***Station Data***: this defines the ground topology and the highway elevation at different locations.

3) ***Zone***: this defines the construction sequence along the highway length.

4) ***Repetitive Activities***: this defines the construction activities.

Cross Section

As known there are wide ranges of cross sections geometry that may used in highway project. Moreover, within a given highway project the cross section geometry may be changed from location to another due to topology condition, traffic flow, speed …etc. HWSDSS has been designed to allow the user to define any number of cross sections within a given project; each cross section geometry is defined by two sets of points (Right and Left points sets). The right points set define the shape of the right side of the highway cross section, while the left set of points defines the shape of the left side. These allow the user to define unsymmetrical cross section. As shown in Figure (5), the points that define both the right and left side are defined relatively to the center point.Eeach point is defined by its distance from the center line (x_i) and the slope (S_i) of the segment line that connect the points i-1, i. As Shown in Figure (5), the following additional attributes are required for defining the highway sloping:

RRPoint, RLPoint: number of points that define the right and left side of the road section respectively (grater or equal than one).

SlopeEx, SlopeEm: the slopes of the road sides in excavation case and embankment case respectively.

WBEx, WBEm: slope break width in excavation case and embankment case respectively.

HBEx, HBEm: slope break height interval in excavation case and embankment case respectively.

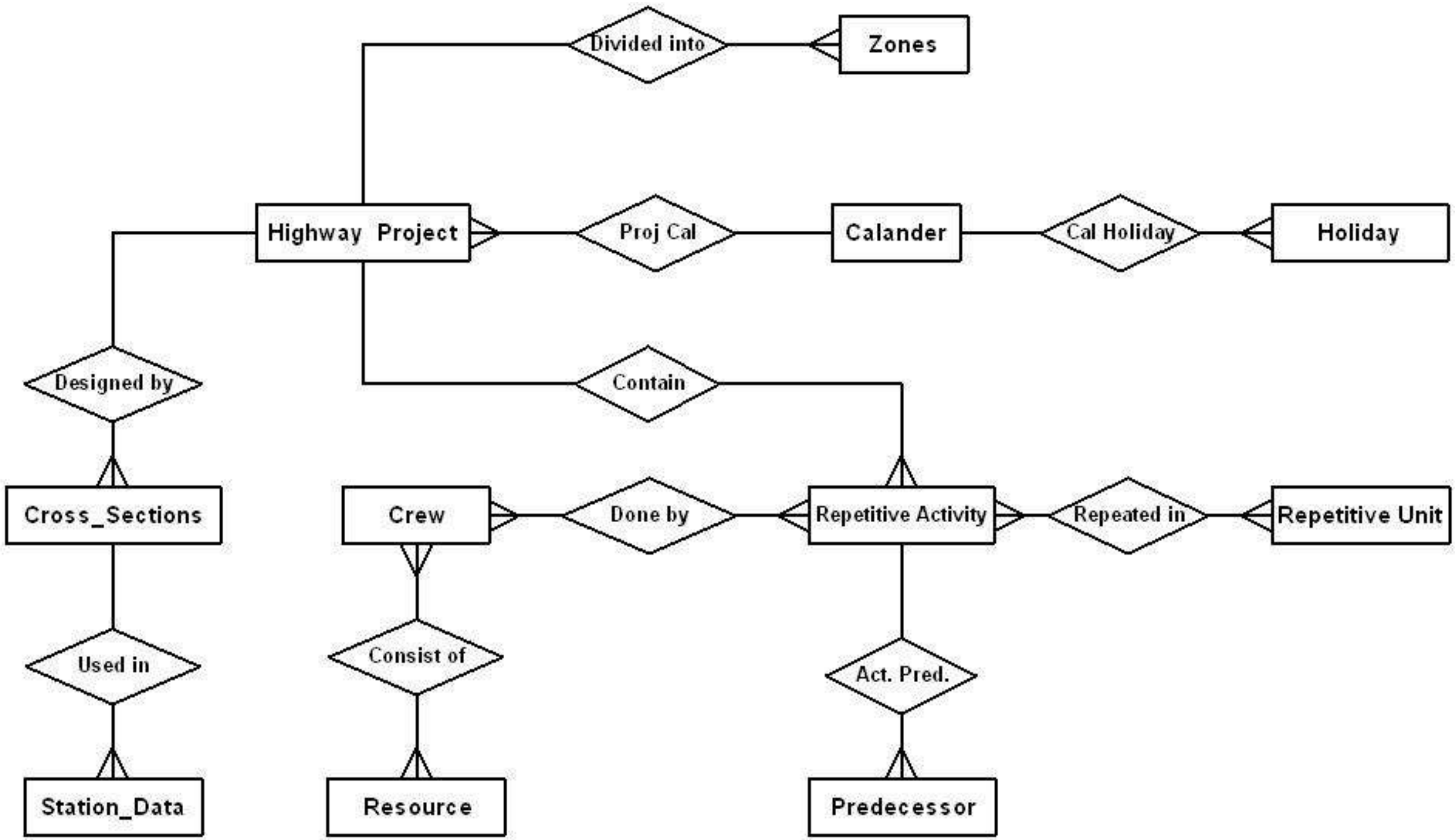


Figure (4) Integrated E-R diagram for HWSDSS Database

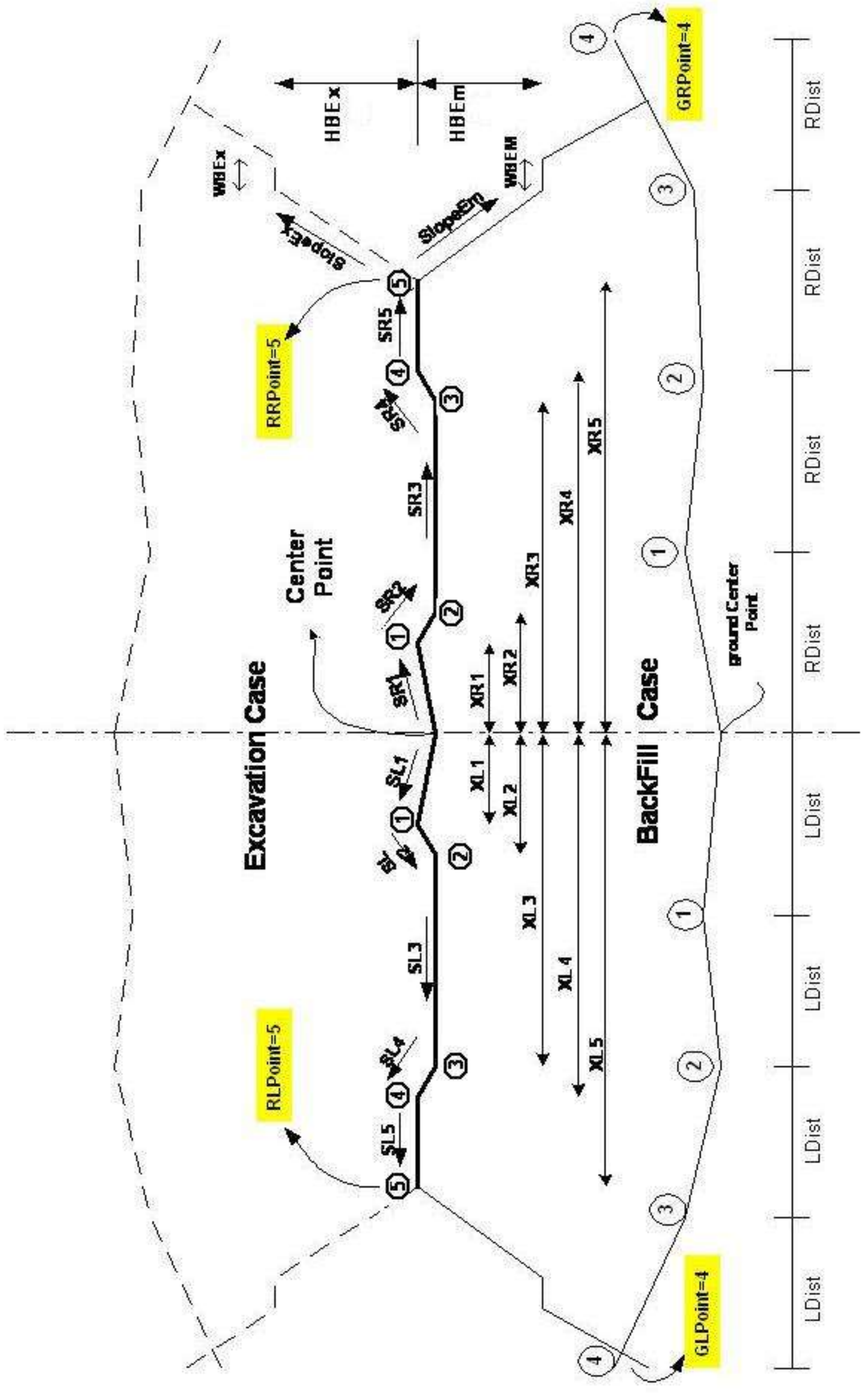


Figure (5) Highway Cross section

Station Data

Each Station Data object represents the ground profile at specific station. Station Data is defined by two sets of points. One set defines the right side of the ground profile, while the other defines the left side. These points are defined by its elevations and the distance between each two successive points as shown in Figure (5). For each station HWSDSS uses the assigned station data, and its associated cross section to calculate the quantity of work for the different activities. For example, excavation volume for the segment that lay between the stations (i) and (i +1) can be calculated as follows:

$$Exv_{i,i+1} = \frac{ExvA_i + ExvA_{i+1}}{2} \times \Delta L_{i,i+1} \qquad (2)$$

Where:

$ExvA_i$, $ExvA_{i+1}$: The calculated excavation area at stations i, i+1 respectively.

$\Delta L_{i,i+1}$: The distance between the stations i, i+1.

Zones

In the proposed DSS Zones, indicate to horizontal spaces, or groups of sequential segments. As shown in Figure (1) HWSDSS distinguishes between two types of zones based on the highway longitudinal section: 1) Excavation zone, sequential segments where the elevation of the highway designed line is greater than the ground elevation. 2) Backfill zone, sequential segments where the elevation of the highway designed line is less than the ground elevation. HWSDSS detects the stations data and perform automatic zoning as shown in Figure (1), to do so it generate additional stations such as stations at points A, B, C by linear interpolation. The generated zones are linked automatically by start-to-finish relationship between each two successive zones. The planner defines the highway construction sequence by changing (or splitting) the generated zones attribute (such as start-station, end-station) and changing zones relationships. Two types of relationship can be defined, ZSF (Zone Start-to-Finish), and ZSS (Zone Start-to-Start). Zones and their relationships only affect the Cut and Fill operation. HWSDSS generates uniform layers (by user specified thickness) in the back-fill zone, these layers extended along the zone length at the layer elevation, and their execution assumed to be layer by layer from the bottom to the top.

Repetitive Activities

Repetitive activities are operations necessary to accomplish the highway project, such as clearing, grubbing, sub-grade, sub-base construction, base course construction, paving, and shoulder construction. Each one of these repetitive activities is automatically sub-divided into activities related to a specific segment of the project. For each repetitive activity object, it is required to define its relationship (that represents the technological dependency) and the available crew formation alternatives.

Optimum Schedule generator module

This module includes routines and functions for generating project activities, and algorithms for scheduling and selecting the optimum crew formation for each repetitive activity. HWSDSS generate the optimum schedule that is corresponding to the planner object function (minimum duration, or minimum cost) using the mixed combinatorial-dynamic programming technique proposed by Naja (2001). In addition, special routine has been designed for scheduling the Cut & Fill operation based on the zone relationships defined by the user. In the back-fill zone the filling activity scheduled by a way illustrated in figure (2).

User interface module

HWSDSS has been implemented using Microsoft Visual basic programming language and the result application run on Microsoft window 95/98 and NT and support user-friendly interface. The user interface of HWSDSS incorporates menus, tool bar, status bar, dialog boxes, entry screens or forms and accepts the keyboard and/or mouse entries in the communication with the user. For estimating and scheduling a given highway construction projects, HWSDSS needs to provide necessary input data by the following order: project data, station data, zone and its relationships, and repetitive activities and its relationships including its possible crew formation alternatives.

Project Data:

General Data: As shown in Figure (6) for a given new project the planner is required to specify a unique *Project Name* (file name), *Project Start Date*, and optionally *Version*, *Project Title*, *Company Name.* In Addition it is required to define the number of right / left points that will be used to define the cross section (RRPoints and RLPoints), the ground profile (GRPoints, Rdist and GLPoints, Ldist) as shown in Figure (7).

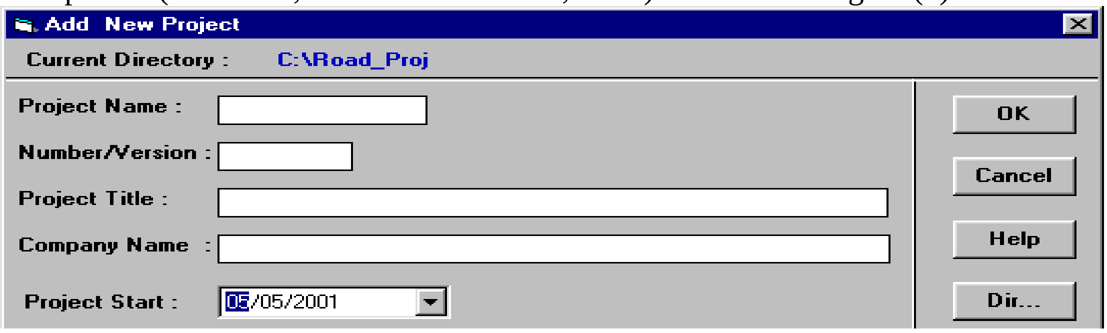


Figure (6) Add New Project Form

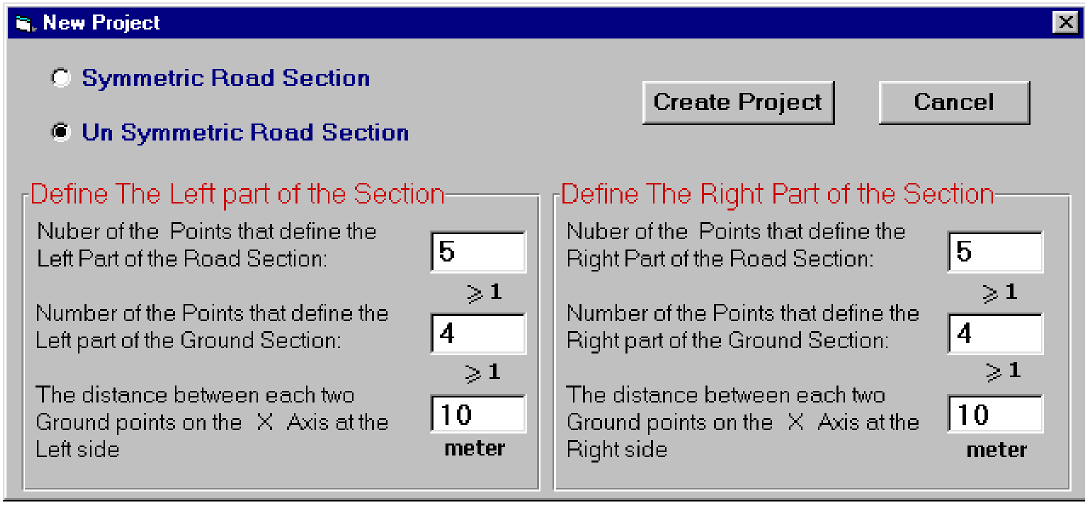


Figure (7) Define Project Section

Project Calendar: By default the application automatically creates a standard workweek calendar for every new project (six working days/week, Friday is weekend). User may modify the generated calendar using the form shown in Figure (8).

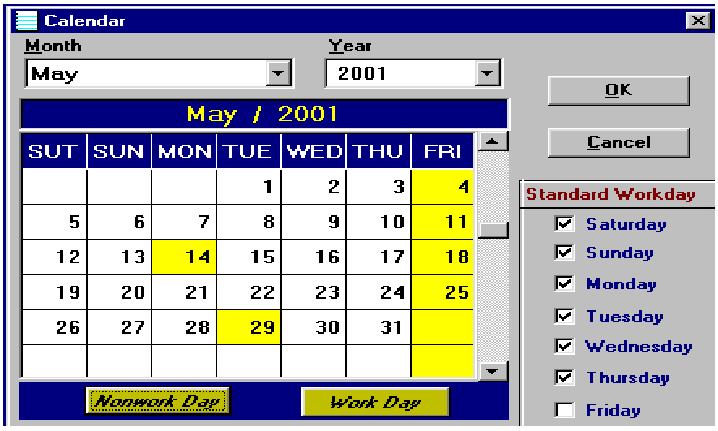


Figure (8) Define Project Calendar

Resources Dictionary: The resources dictionary contains a list of all resources and its cost information as shown in Figure (9). Once the resources are defined for the project, they can be assigned to individual crew formation alternatives. Resource cost rate may be entered using *Cost Per Day* or *Cost Per Competed Unit*. Resources cost rate is required especially when the optimization objective is the minimum project overall cost.

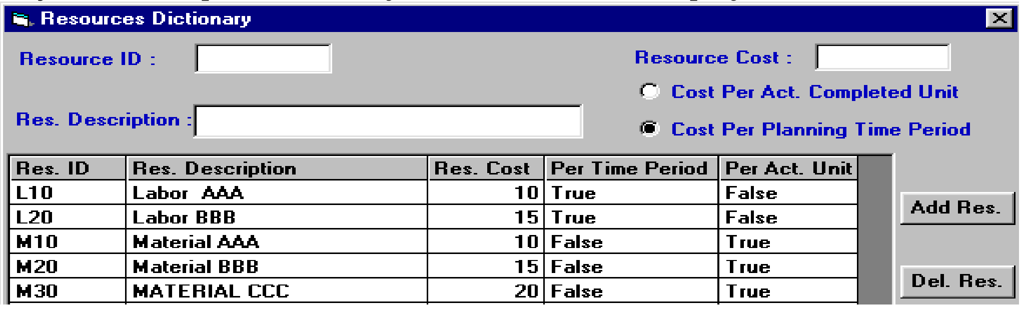


Figure (9) Building Resources Dictionary

Repetitive Activities: as shown in Figure (10) user select the repetitive activities of current project (right pan) from the built in activities dictionary (left pan). Highway Project dictionary is designed with two hierarchy levels, Project Phases for the first level, and repetitive activities for the second level. HWSDSS Allow the user to Add, Edit, delete items in both level.

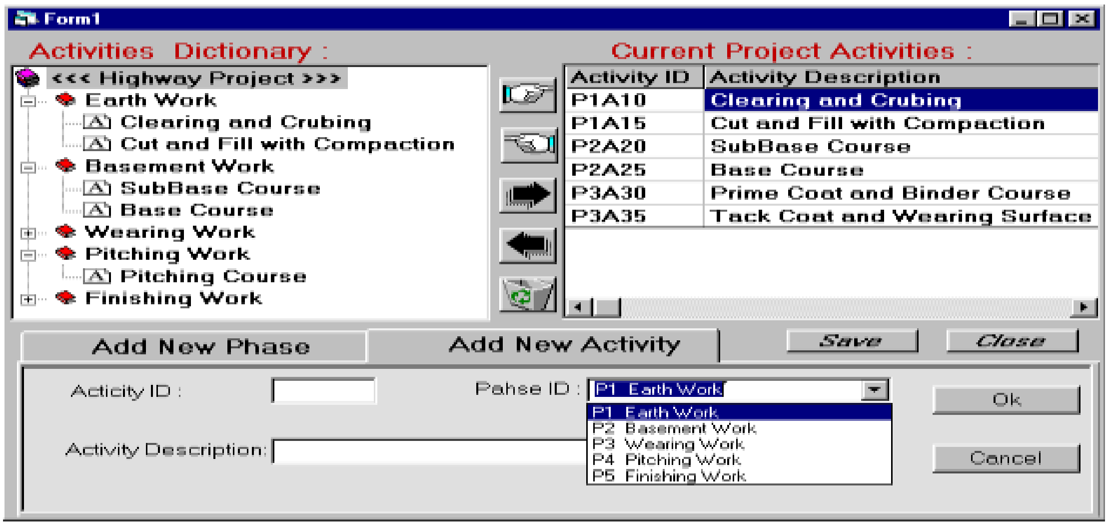


Figure (10) Repetitive Activities Dictionary

Stations Data:

Designed Cross Sections: The highway designed cross sections are defined in the form shown in Figure (11). Each cross section is uniquely identified by the attribute *Road_Sec_No* and may be assigned to many stations, for each station it is enough to assign the cross section type (*Road_Sec_No)* and the highway elevation at the centerline (*Road_Y$_0$*). The remaining cross-section point's elevations can be calculated using the equation (2) and (3).

Left Side points: $YL_i = YL_{i-1} + SL_i(XL_i - XL_{i-1})$ For $i = 1, 2, ..., \text{RLPoint}$ (3)

Right Side points: $YR_i = YR_{i-1} + SR_i(XR_i - XR_{i-1})$ For $i = 1, 2, ..., \text{RRPoint}$ (4)

Where:

YL_i : the elevation of the left point i . SL_i : the slope between left points i and i-1

XL_i : the distance between the left point i and the section center line.

YR_i : the elevation of the right point i . SR_i : the slope between right points i and i-1

XR_i : the distance between the right point i and the section center line.

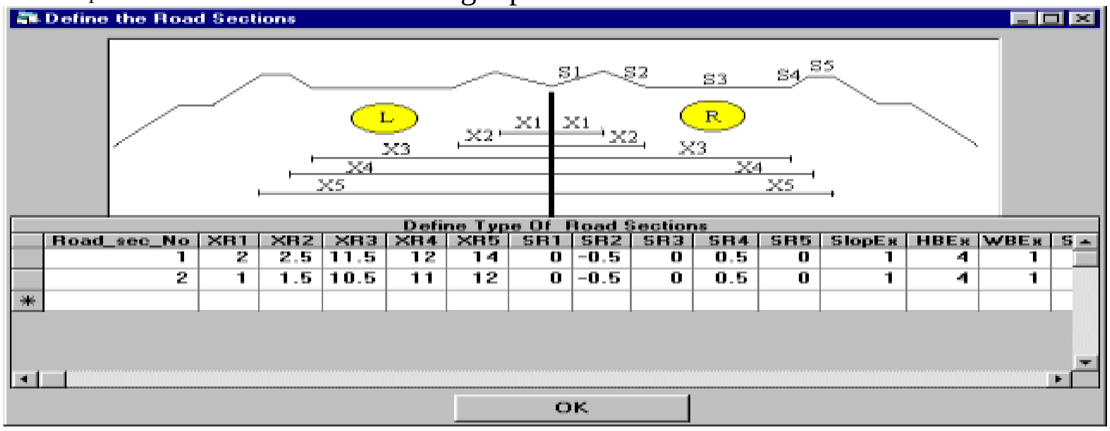


Figure (11) Define the highway Cross Sections

Stations Ground Profiles: All project stations should be defined in the form shown in Figure (12). Each station defined by its unique name, and its distance from the project start point, and the highway cross section type (Road_Sec_No, Road_Y0) at this station, and the ground profile by defining the left / right sets of ground points (for example if the user assigned GRPoints = GLPoints=4 and Rdist =Ldist =10 the ground profile defined by YL40, YL30, YL20, YL10, Y0, YR10, YR20, YR30, YR40).

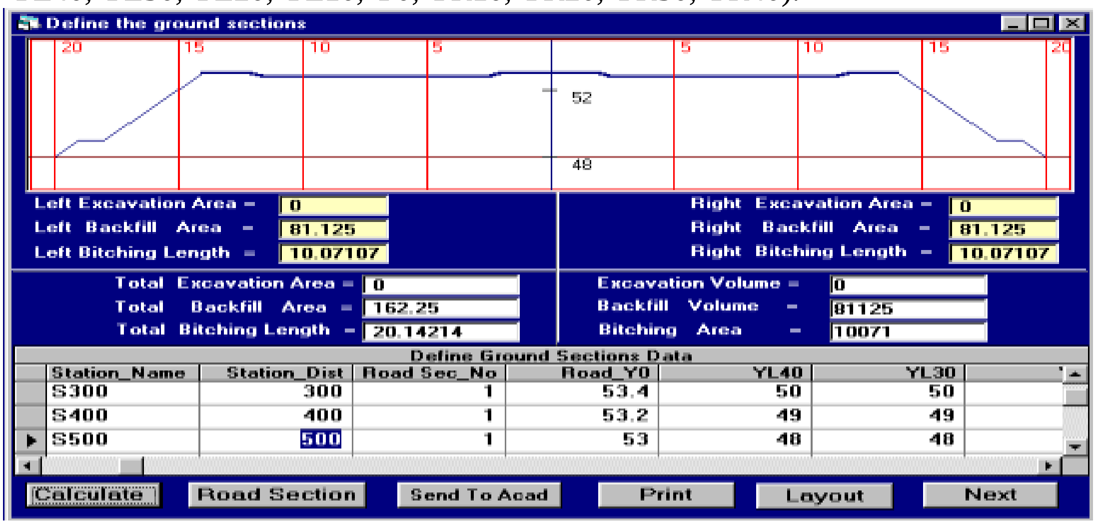
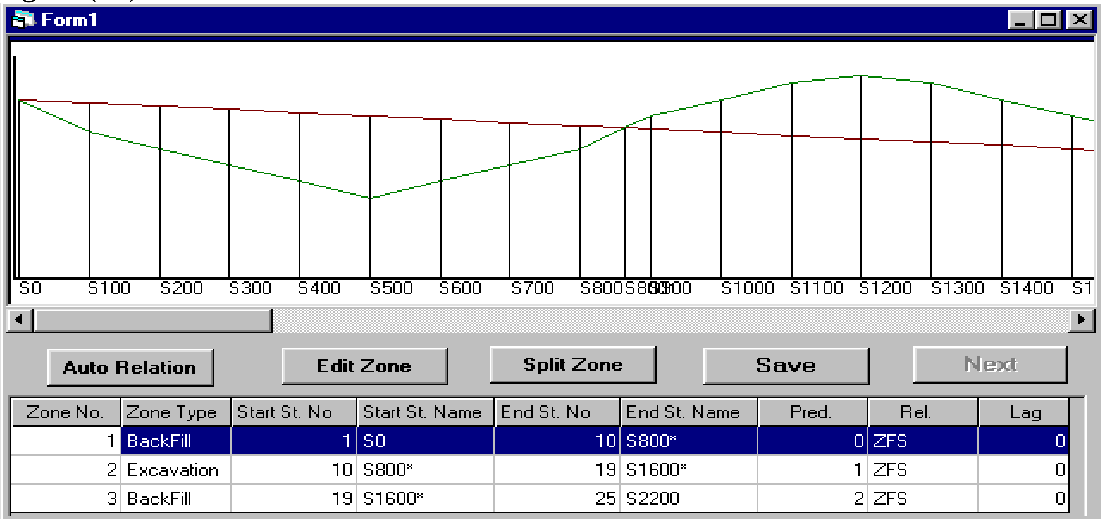


Figure (12) Define the highway Stations

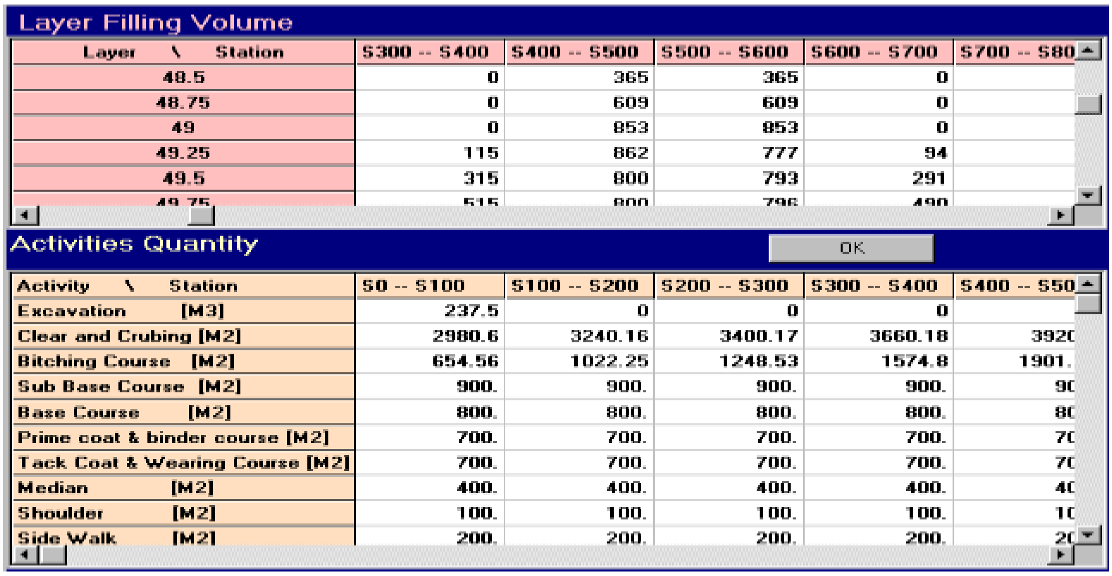
Zones Data:

At this point HWSDSS can detect the Stations data provided by the user, and generate the longitudinal section and automatically zone the highway project as shown in Figure (13). HWSDSS automatically link each two successive zones by ZFS (Zone-Finish-Start) relationship. User may modify/split the generated zone by modifying the *Zone-Start-Station*, *Zone-End-Station* and the zone relationship and its associated lag. After modifying or accepting the generated zones, HWSDSS can automatically perform the quantity take-off for all selected repetitive activities in each segment of the undertaken project as shown in Figure (14).



Zone No.	Zone Type	Start St. No	Start St. Name	End St. No	End St. Name	Pred.	Rel.	Lag
1	BackFill	1	S0	10	S800*	0	ZFS	0
2	Excavation	10	S800*	19	S1600*	1	ZFS	0
3	BackFill	19	S1600*	25	S2200	2	ZFS	0

Figure (13) Zones and its relationships



Layer Filling Volume

Layer \ Station	S300 -- S400	S400 -- S500	S500 -- S600	S600 -- S700	S700 -- S80
48.5	0	365	365	0	
48.75	0	609	609	0	
49	0	853	853	0	
49.25	115	862	777	94	
49.5	315	800	793	291	
49.75	515	800	796	490	

Activities Quantity

OK

Activity \ Station	S0 -- S100	S100 -- S200	S200 -- S300	S300 -- S400	S400 -- S50
Excavation [M3]	237.5	0	0	0	
Clear and Crubing [M2]	2980.6	3240.16	3400.17	3660.18	392
Bitching Course [M2]	654.56	1022.25	1248.53	1574.8	1901.
Sub Base Course [M2]	900.	900.	900.	900.	9
Base Course [M2]	800.	800.	800.	800.	8
Prime coat & binder course [M2]	700.	700.	700.	700.	7
Tack Coat & Wearing Course [M2]	700.	700.	700.	700.	7
Median [M2]	400.	400.	400.	400.	4
Shoulder [M2]	100.	100.	100.	100.	1
Side Walk [M2]	200.	200.	200.	200.	2

Figure (14) Quantity take-off analysis

Repetitive Activities Data:

Repetitive Activity Relationships: Relationships indicate dependencies between activities. HWSDSS require defining only the repetitive activities relationships in a typical segment or unit. The generated discrete activities (in each segment) will inherit these defined relationships. Activity relationships could be established in term of predecessors or successors as shown in Figure (15). HWSDSS support four type of relationships FS

(Finish-to-Start), SS (Start-to-Start), FF (Finish-to-Finish), and SF (Start-to-Finish) and accept associated positive or negative lag between any two related activities.

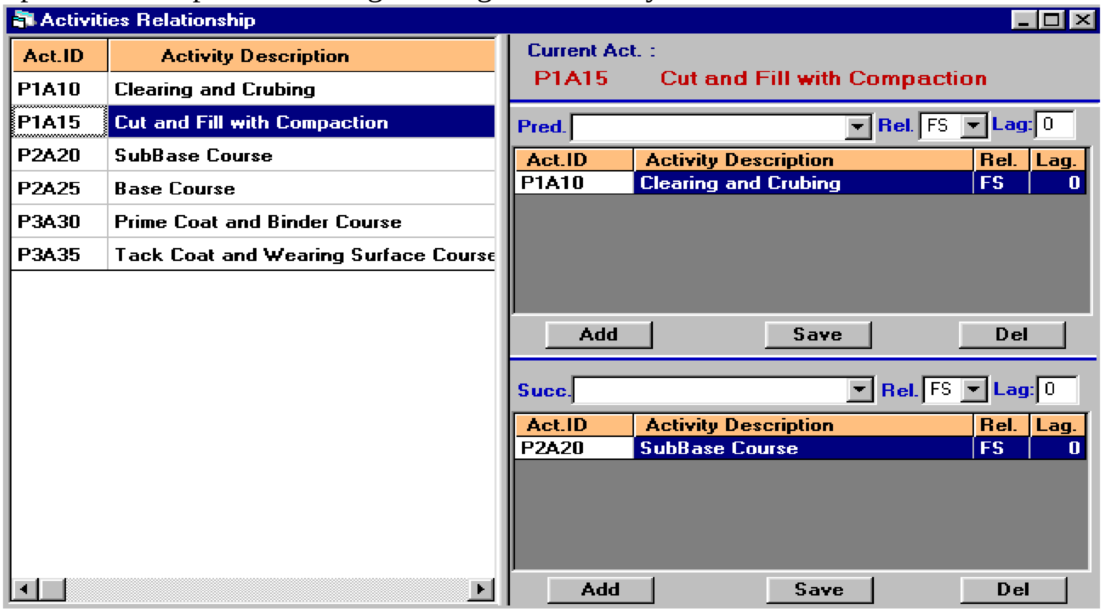


Figure (15) Define repetitive Activities relationships

Crew Formation Alternatives: Often, there is more than one crew utilization option that can be used to construct a repetitive activity. Each of these crew utilization options can be identified as a unique crew formation to construct the activity. HWSDSS enables the user to specify up to 10-crew formation alternative for each repetitive activity, each crew formation may consist of a different combination of resources (Labors, Equipment, and Materials which are defined in the project resources dictionary). As shown in Figure (16) each crew formation is associated with its productivity rate per day, which is used to calculate the activity duration that is associated with this crew formation alternative.

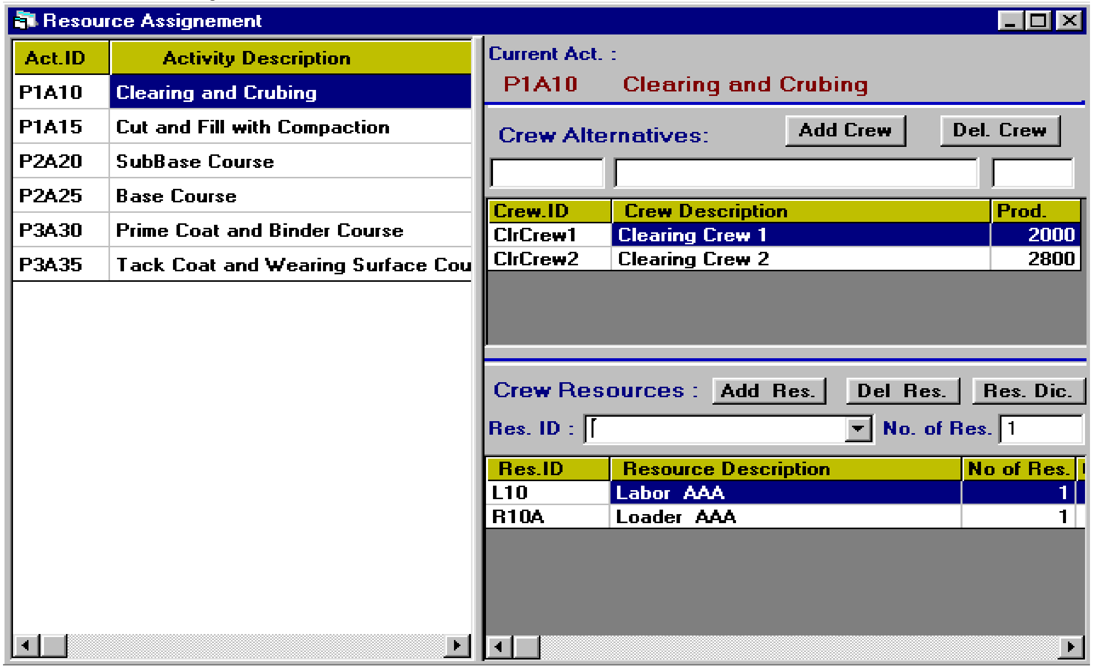
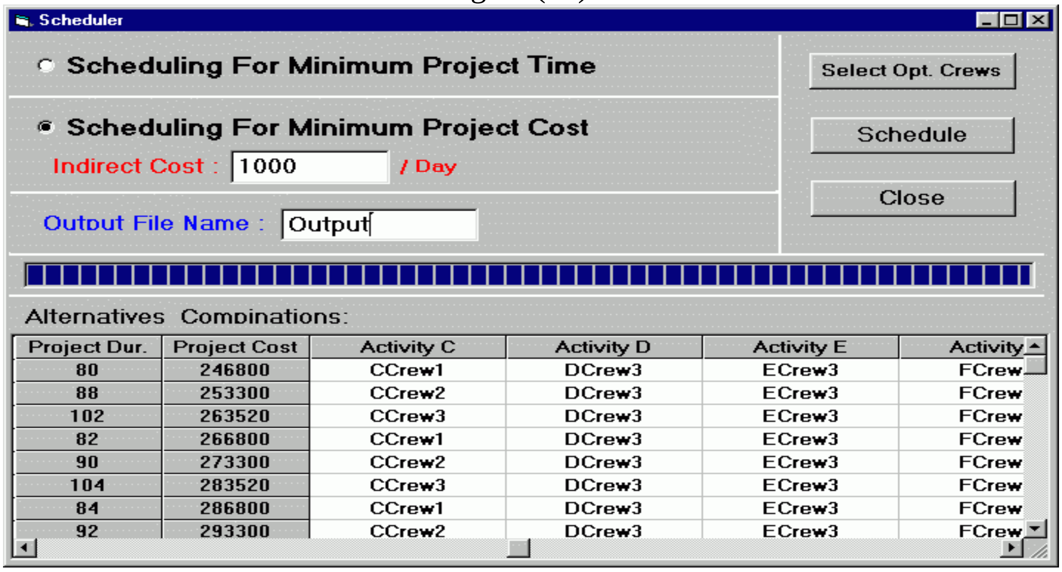


Figure (16) Crew Formation Alternatives Assignment

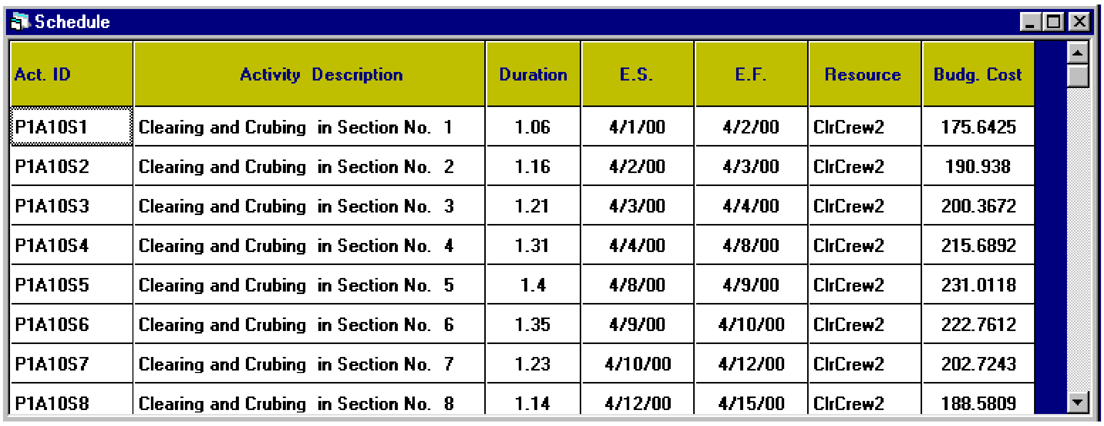
Project Scheduling

After completing all the necessary input data, HWSDSS can perform the scheduling process during two stages: First, it utilize the mixed combinatorial-dynamic programming technique proposed by Naja (2001) to generates the optimum possible combinations based on the planner object function (minimum project duration, or minimum project cost) as shown in Figure (17). Second, it also generates detail schedule that corresponding to the user selected combination as shown in Figure (18).



Project Dur.	Project Cost	Activity C	Activity D	Activity E	Activity
80	246800	CCrew1	DCrew3	ECrew3	FCrew
88	253300	CCrew2	DCrew3	ECrew3	FCrew
102	263520	CCrew3	DCrew3	ECrew3	FCrew
82	266800	CCrew1	DCrew3	ECrew3	FCrew
90	273300	CCrew2	DCrew3	ECrew3	FCrew
104	283520	CCrew3	DCrew3	ECrew3	FCrew
84	286800	CCrew1	DCrew3	ECrew3	FCrew
92	293300	CCrew2	DCrew3	ECrew3	FCrew

Figure (17) Scheduling optimization



Act. ID	Activity Description	Duration	E.S.	E.F.	Resource	Budg. Cost
P1A10S1	Clearing and Crubing in Section No. 1	1.06	4/1/00	4/2/00	ClrCrew2	175.6425
P1A10S2	Clearing and Crubing in Section No. 2	1.16	4/2/00	4/3/00	ClrCrew2	190.938
P1A10S3	Clearing and Crubing in Section No. 3	1.21	4/3/00	4/4/00	ClrCrew2	200.3672
P1A10S4	Clearing and Crubing in Section No. 4	1.31	4/4/00	4/8/00	ClrCrew2	215.6892
P1A10S5	Clearing and Crubing in Section No. 5	1.4	4/8/00	4/9/00	ClrCrew2	231.0118
P1A10S6	Clearing and Crubing in Section No. 6	1.35	4/9/00	4/10/00	ClrCrew2	222.7612
P1A10S7	Clearing and Crubing in Section No. 7	1.23	4/10/00	4/12/00	ClrCrew2	202.7243
P1A10S8	Clearing and Crubing in Section No. 8	1.14	4/12/00	4/15/00	ClrCrew2	188.5809

Figure (18) Scheduling Details

Conclusions and Recommendations:

A decision support system for estimating and scheduling optimization of Highway construction projects has been presented. The developed DSS automates the process of quantity take-off for all project activities based on the ground topography data and the designed cross-sections of the highway. In addition, it provides least project cost or least project duration schedules that complies with precedence relationships, crew work continuity constraints. The proposed DSS can be used by contractors working in the field of highway construction projects. Future extensions and modification are recommended to be added to the system such as considering risk and uncertainty in estimating activities durations and costs, and allowing the system to communicate with the available scheduling software packages such as Primavera or MS Project.

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