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DEVELOPING THE LSM $_{VPR}$ SCHEDULING METHOD FOR SCHEDULING HIGHWAY CONSTRUCTION PROJECTS BASED ON EFFECTIVE FACTORS ON EMBANKMENT ACTIVITY PRODUCTIVITY

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ABSTRACT

Highway construction projects are one of the most important construction projects in the world. Therefore predicting the time of these kinds of projects is important. Basically highway projects are including few activities which are repeating along the horizontal direction. One of the best methods for scheduling these types of projects is linear scheduling method. The repetitive nature of the highway activities is a good reason for schedulers to use linear scheduling methods in order to estimate the time of the project. One of the most important factors in linear projects is considering the effect of the activities productivity on scheduling. The first part of the research has been proposed to quantify the main equation of the identified factors for predicting the daily production rates of the embankment activity. The second part is scheduling the highway construction projects by developing the LSMvpr method based on the application of the embankment activity productivity equation. The purpose of the research is to develop the LSMvpr method for scheduling the highway construction projects by considering the concept of activity productivity in the shape of an equation varying by independent variables changes. By the use of multiple regression analysis the coefficients of affecting factors have been calculated in order to gain a production rate equation for predicting the embankment activity productivity. A software package has been presented for scheduling a highway construction project by coding in MATLAB. The offered software used for validating the model for scheduling the highway construction projects.

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KEY WORDS: highway construction projects, linear scheduling, activity productivity, multiple regression analysis

1. INTRODUCTION

Nowadays in different type of projects one of the most important subjects in construction is the ability of predicting the time of the different types of projects. Therefore to achieve this goal several scheduling methods have been presented during the past few years. Scheduling methods in generally speaking divided into two groups first one is network scheduling methods and the second one is the linear scheduling methods. Some of the construction projects are including few activities repeating along the alignment of the project. These kinds of projects are divided into two main groups, projects with repetitive activities in horizontal alignment such as highway construction projects and projects with repetitive activities in vertical alignment such as construction of high rise buildings. The main factor in the repetitive projects is the production rate of the activities. In this research based on data of a highway construction project in city of Mashhad in Iran, an equation has been calculated with the help of multiple regression analysis in order to predict the daily production rates of this activity (production rate of activity and activity productivity are the same in our paper, so they could be used as each other). The main purpose of this research is to develop the LSMvpr according to the effect of the embankment activity productivity in order to schedule the highway construction projects.

2. PREVIOUS RESEARCHES ON LINEAR SCHEDULING METHODS

Based on the previous section the methods for scheduling the construction projects are network scheduling methods and the linear scheduling methods. Network-based scheduling methods, such as critical path method (CPM), have major drawbacks when applied to scheduling of repetitive projects [1–4] such as predicting the wrong duration of the project. In linear scheduling methods activities are defined as lines and the scheduling is done by drawing the lines with considering the buffers between the activities. In 1981 linear scheduling method(LSM) was first presented by Johnston [5]. Johnston for the first time used the “linear scheduling method (LSM)” to the highway construction industry [5].

Chrzanowski and Johnston [6] contrasted CPM with LSM utilizing an as-built highway schedule. The most important advantage of the LSM was the simplicity of this method. The authors mentioned in their paper that the user can “receives fairly detailed information without being confronted with the numerical data and degree of abstraction found in network methods. For complex projects with discrete activities such as high rise buildings, a network diagram should be used to model the interrelationship and sequencing of activities. In the other hand for projects with few activities which are repeating along the project, the linear scheduling method is offered for scheduling the projects. In conclusion, the authors noted that LSM was best method in order to complete CPM.

Harmelink [7] developed a model of linear scheduling in conjunction with an Autocad based program. His work focused on two important aspects of linear scheduling: a) proving computerization of linear scheduling is possible and b) illustrating procedures to identify the controlling activity path in the schedule. In CPM, the critical path of the activities is defined as the longest path, which has the maximum time duration through the sequence of activities to the end of the project. In LSM, the critical path is called the controlling activity path. Harmelink introduced three factors in order to predict the controlling activity path.

These key features are the least time interval (LT), coincident duration, and the least distance interval (LD). The least time interval is "the shortest time interval between any two consecutive activities". The coincident duration is "an interval in time during which the two activities connected by the least time interval are both in progress." Lastly, the least distance interval is "the shortest distance between any two activities that lies within the coincident duration interval and intersects the least time interval."

El-Sayegh [8] developed deterministic and probabilistic models for calculating resource based linear schedules. The deterministic model can be used to produce a linear schedule based solely on user input. The probabilistic model may be used to produce a linear schedule based on Monte Carlo simulation, which accounts for variability and uncertainty of construction projects. The models were included in a windows-based software package named "Linear Construction Planning Model" (LCPM).

Harris and Ioannou [9] developed the linear scheduling method in order to schedule the projects with repetitive activities. Actually in this method repetitive activities defined as units which are repeating along the project.

Lucko [10, 11] presented the productivity scheduling method (PSM), in his method two factors have been considered one of them is the production rates of the activities and the other one is using singularity functions in order to reach an equation for mathematically draw the lines in the linear scheduling method. The creativity of this method is the considering of the variation of the production rates of different activities in the form of an equation so that the scheduler can draw the lines (activities) by the use of the singularity functions. The slope of the each line can be defined as the production rate of the activity which can changes during the time of the project.

Duffy et al. [12] introduced linear scheduling model with varying production rates (LSMvpr) in a paper. In this paper author defined a new method for linear scheduling in which the concept of working window for the first time has been presented. In this method the slopes of the lines are the production rates of the activities. The algorithm and the calculation for this method are introduced in the next section. The different types of linear scheduling methods have been shown in Table 1.

Based on the previous researches, the accuracy of the scheduling of the projects with few activities which are repeating along the project is based on the production rates of the activities. Different methods such as LSMvpr are presented in order to scheduling these projects. Highway construction projects are one of those projects which contains activities with repetitive nature. In this research the purpose is to improve the LSM_{vpr} in order to schedule the highway projects. The different steps of this research is shown in a flowchart which is presented in Figure 1.

Table 1: Types of Linear Scheduling Methods

Scheduling Methods	Researchers (Year)(Resource)
Linear Scheduling Method	(Johnston , 1981) (5)
Linear Scheduling Method	(Chrzanowski and Johnston, 1986) (6)
Linear Scheduling Method	(Vorster, Beliveau and Bafna, 1992) (13)
Linear Scheduling Model	(D. J. Harmelink, 1995) (7)
Linear Scheduling Model	(Mattila, 1997) (14)
Repetitive Scheduling Method	(Harris and Ioannou, 1998) (9)
Linear Scheduling Model	(David J. Harmelink and Rowings, 1998) (15)
Linear Construction Planning Model	(El-Sayegh, 1998) (8)
Linear Scheduling Model	(Liu, 1999) (16)
Linear Scheduling Method	(Herbsman, 1999) (17)
Visual Linear Scheduling Model	(Yamin, 2001) (18)
Linear Scheduling Method	(Cosma, 2003) (19)
Linear Scheduling Model	(Yen, 2005) (20)
Productivity Scheduling Method	(Lucko, 2009) (11)
Linear Scheduling Model with varying productivity Rate	(Duffy, 2011) (12)

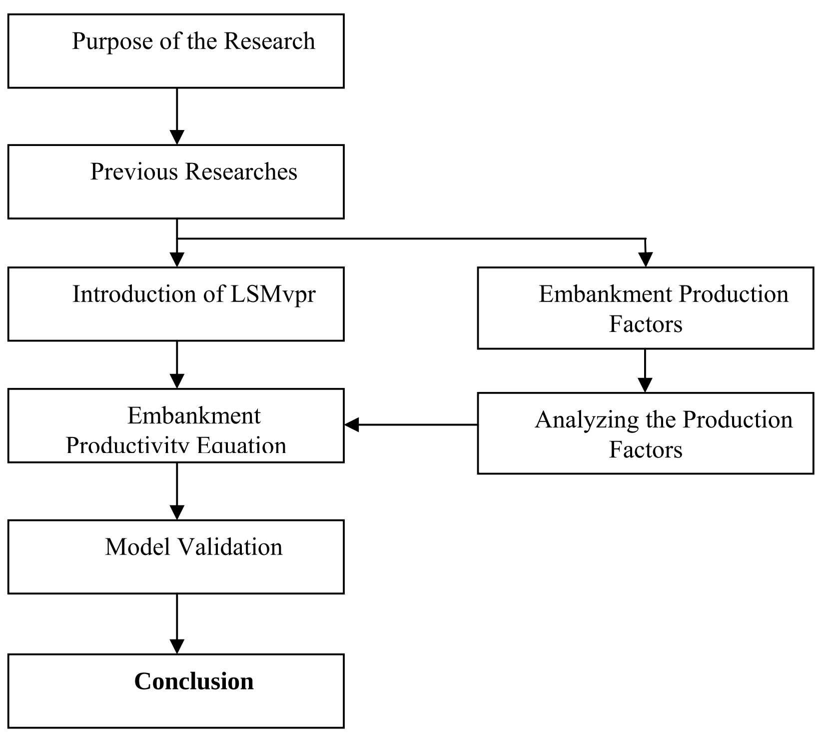

Figure 1. Flowchart of the methodology

3. LINEAR SCHEDULING MODEL WITH VARYING PRODUCTION RATE (LSM_{VPR})

LSM_{vpr} is a linear scheduling method based on the production rates of the activities. This method is a mathematical method for drawing the activities by considering the production rates of the activities (activity productivity). The main concept of this method is working window.

3.1. Working window (ww)

The time location chart is devided into smaller rectangles which are called working windows. In the other word the working windows (ww) are similar particular spaces of time and location in the linear scheduling diagram. The most important thing in these windows is that the slope of the lines through the each of the windows must be constant. In the other word the production rate of each activity in the working window must be constant. In this framework the user can easily recognize where and when the production rate of an activity changes.

3.2. Main parameters of lsm_{vpr}

For drawing the lines (activities) and determining the coordinates of the exit point of the line from the working window in the linear scheduling diagram three factors are defined:

1- Distance Remaining (DR): DRij = WWLEi – Xn
2- Time Remaining (TR): TRij = WWTEj – Yn
3- Distance Travelled in Time Remaining (DTTR): DTTRij = PRij * TRij

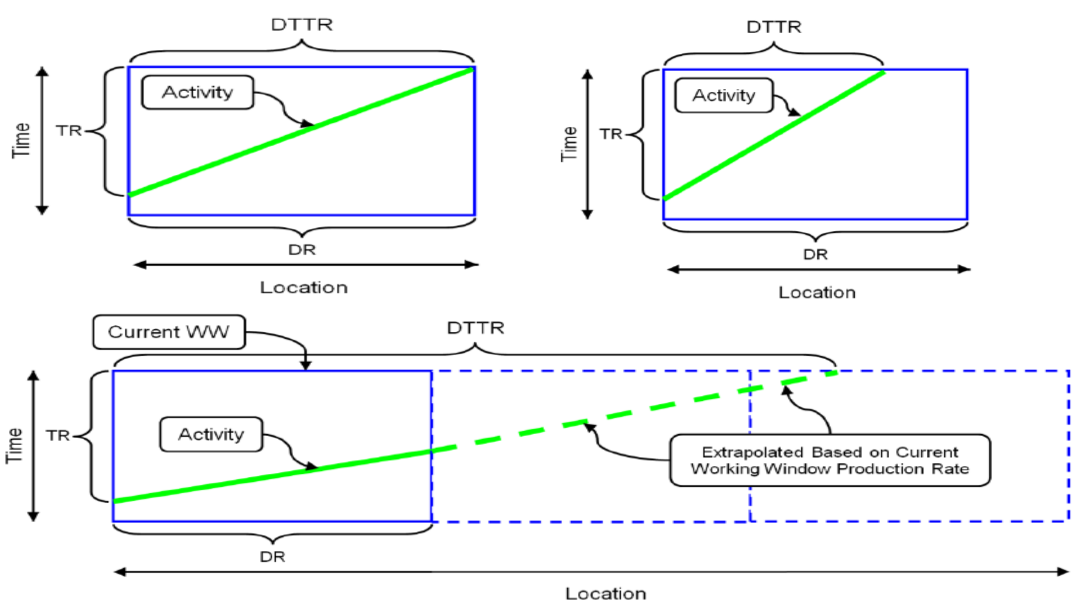

Figure 2. The Types of the Exit Point of the Line from the Working Window [12].

The (DTTR) can then be compared with the DR to determine the exit location. The following three outcomes can occur:

1) DTTRij = DRij: Activity exits at the intersection of the top time axis and right distance axis of the working window

2) DTTRij>DRij: Activity exits at the right distance axis of the working window

3) DTTRij<DRij: Activity exits at the top time axis of the working window

These three cases has been showed in Figure 2.

Based on the production rates of each activity and considering the time buffers between the activities the lines is drawn and the process of scheduling in order to predict the time duration of the project is done.

4. PRODUCTION FACTORS

Based on the findings by Kuo [21] the main factors affecting the different activities productivities of highway projects are defined. These factors are divided into 3 levels presented in Figure 3:

1-project level

2-work zone level

3-work item level

Each of the levels is including different items. In this research the factors that are related to the embankment activity are studied and investigated.

4.1. Project level

Some of the factors influencing the embankment activity productivity in project level are described as follow:

1- Project Type: Type of the project depends on the volume of the work and strategy of traffic control can has an effect on embankment production rate.

2- Project location: this factor with considering the traffic condition can change the production rate of the activity.

3- Traffic flow: the high rate of traffic flow in most of the times can reduce the efficiency of the highway construction machinery that results in the reduction of the production rate of the embankment activity.

4- Project complexity: in projects with more technical complexity, the rate of impact between human resources increases that this condition results in the reduction of the production rate.

6- Contractor management skill: Contractors with higher management skill can monitor the project site better and therefore economically assign resources in order to increase the production rate.

4.2. Work zone level

1- Accessibility to work zone area: In projects with shorter transporting distance and better road condition we Can Have the higher rate of production rate.

2- Interference and impact of the work zone: The bigger the area of the work zone the less interference and finally the higher production rate gained.

3- The effect of drainage of the work zone: In areas with the soils with less drainage capability the production rate of the embankment activity will be decreased.

4.3. Work item level

1- Work area: In projects with repetitive activities especially highway construction projects daily production rates in places with bigger area is much higher.

2- Soil conditions: Soil condition with considering the impaction of the soil in order to achieve desired density can affect the production rate.

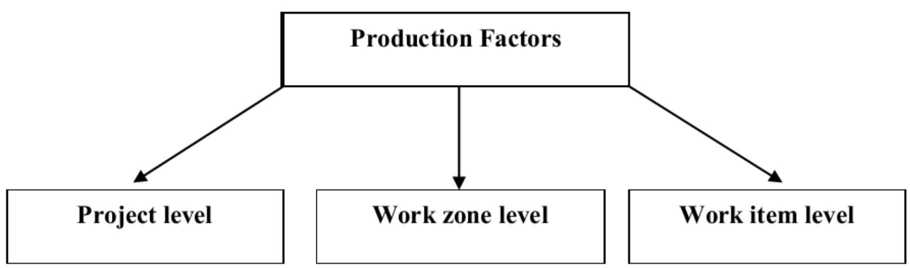

Figure 3. Levels of the Production Factors

3.4. Investigated factors

Based on the previous researches and the experts issues the effective factors affecting the embankment activity productivity are mentioned in Table 2.

Table 2: The Production Factors of the Embankment Activity

Embankment Production Factors		
Project Level	**Work Zone Level**	**Work Item Level**
Project Conditions	Work Zone Area	Work Continuance
Traffic Flow	Work Zone Accessibility	Number of the Highway Projects' Machinery
Weather Conditions		Volume of the Construction Trash Materials
Transportation Distance	Work Zone Congestion	Efficiency of the Machinery
		Volume of the Construction Trash Materials
Contractor Management Skill	Work Zone Slope	Soil Condition Driver Skill

5. DATA ANALYSIS

Different researches have been made for analyzing the production rate of the activities of the several projects. The process of analyzing the variables is based on [21] and [22] researches.

Series of questionnaires have been developed. In the questionnaires all of the 16 items which have been shown in Table 2 are mentioned. These questionnaires have been distributed among the experts of the highway construction companies and transportation engineers in Mashhad city in Iran in order to find the most important variables which are affecting the production rate of the embankment activity. The experts choose a number from 1 to 16 for each of the items based on their priority and importance from their point of view. At last by the use of multiple regression analysis based on the questionnaires, from these 16 factors 7 of them have been defined as the key factors. These variables are:

1. Work zone area
2. Number of the highway projects machinery
3. Weather condition
4. Driver skill
5. Work continuance
6. Contractor Management Skill
7. Work zone Congestion

Using the regression analysis the linear relationship between independent variables and the dependent variable is presented in a form of an equation.

5.1. Multiple regression analysis

In regression analysis we are looking for an equation and analyzing the estimated equation, in order to determine the quantity of the dependent variable by the help of independent variables. Assuming that there is a linear relationship between the two quantitative variables a regression equation can be defined as $y = a + b. x$ called linear regression.

In some cases two or more independent variables are affecting the dependent variable. In these situations we have to use multiple regression analysis. In multiple regression analysis the assumption of the linear relationship between the variables is established. A model for estimating a multiple regression analysis with two independent variables is defined as $Y_i = b_0 + b_1 \times X_{1i} + b_2 \times X_{2i}$ in which X_{1i} and X_{2i} are independent variables and Y_i is dependent variable.

Coefficient of determination or R^2 is a criterion for measuring the accuracy of the regression line which is plotted. The amount of R^2 is between 0 and 1, and shows the rate of the variations of the dependent variables. The R^2 formula is presented below:

$$R^2 = \frac{1 - \sum e_i^2}{\sum \left(Y_i - \bar{Y} \right)^2} \quad (1)$$

The multiple regression analysis is for determining the rate of influence of the each of the independent variables on dependent variable. The independent variables are not in relation with each other but the variation of the each of them can change the quantity of the dependent variable. The dependent variable is the answer of the multiple regression analysis. In this research independent variables are the effective production variables which are influencing the production rate of the embankment activity and the production rate of the embankment activity is the dependent variable.

5.2. Steps of the linear regression analysis

Linear regression analysis includes different steps as below:

1. To make sure that enough data points exist for the analysis
2. Perform check to ensure the dependent and independent variables are approximately normally distributed.
3. Utilize box plots and analyze standardized residuals to remove outliers.
4. Fit a regression model.
5. Check for co-linearity among the variables selected for the model.
6. Check the validity of the model utilizing R^2.

Based on a study in regression analysis [23], requested size of the sample for regression analysis can be determined by the use of 4 factors (Table 3). These factors are: α (the probability of making a type I error), 1-β (one minus the probability of making a type II error), R^2, and number of predictors. Table 1.displays the required sample sizes to test the hypothesis that the population multiple correlation equals zero with a power (1-β) of 0.8 and α of 0.05 based on power analysis.

Table 3: Required sample size

Number of predictors	Sample sizes based on power analysis		
	Small R^2=0.02	Medium R^2=0.13	Large R^2=0.26
1	390	53	24
2	481	66	30
3	547	76	35
4	599	84	39
5	645	91	42
6	686	97	46
7	726	102	48
8	757	108	51
9	788	113	54
10	844	117	56
15	952	138	67
20	1066	156	77
30	1247	187	94
40	1407	213	110

In this paper the regression analysis and the calculations are done by the spss11 software. Because of the importance of the embankment activity in highway construction projects the regression analysis has done for this activity. The reasons for choosing this activity as a main activity for predicting productivity (production rate) is that the embankment activity is continuing and repeating during the project and also the activity is a predecessor for the other activities in highway projects. The rate of changes of the daily productivity of embankment activity is much higher than the other activities because of the changes in the depth and slopes of the land. Therefore this activity has been chosen for regression analysis in order to reach an equation for predicting the daily production rate of the embankment activity.

Based on a highway project which is located in city of Mashhad in Iran the data has been collected from the daily reports and monitoring the project. The regression analysis and the equation is presented in the following chapters.

5.3. The investigated highway project information

The highway project which has been studied in this research is located in the eastern part of the beltway of the Mashhad city in Iran. The main activities of this project are divided into three groups. The activities are; the embankment activity, the sub-base activity and finally the base activity. The width of the highway is 14 meters which is divided into two similar lanes with the width of 7 meters. The materials of the sub-grade and the embankment activity are the same so that these two activities are introduced as the embankment activity. Each of the sub-base and the base activities are distributed in two layers. The thickness of each layer is about 16 centimeters. The embankment activity is considered as the main activity of this project, because the variation rate of activity volume is more than the other two activities. Therefore in this research an equation based on the regression analysis has been used for predicting the productivity of the embankment activity. For the sub-base and base activities two average production rates has been used in order to schedule the project.

5.4. Embankment productivity equation

As mentioned before 7 variables have been chosen for regression analysis in order to reach an equation for predicting the productivity of embankment activity. After first analysis on the variables it is found that unlike the first thought the number of the highway projects machinery doesn't have tangible effect on the production rate of the embankment activity. The contractor management skill factor is also doesn't affect the production rate of the activity because the changes of this factor during the project is too low. There are particular human resources in contractor team which are constant during the project. The work zone area factor and Work zone Congestion are inversely related to each other so one of the factors is used in order to reach the production equation. Finally the key factors which are affecting the production rate of the embankment activity are: work zone area, Weather condition, Work continuance, Driver skill.

The regression analysis was done on the variables based on the empirical data of the highway project in Mashhad and eventually the embankment productivity equation is defined as below which is derived from the output of SPSS11 (Table 4). In equation 2 the parameters PR, W. AREA, TEMP, DVR.SKILL and WK.CON are the abrivation of Productivity (Production Rate), Work Area, Temperature, Driver Skill and Work

Continuance, respectively.

$$PR = 24.456 \times W.AREA - 0.369 \times TEMP + 14.722 \times DRV.SKILL - 2.995 \times WK.CON + 9.017 \quad (2)$$

Table 4: Coefficients of the embankment production rate equation

Model	Coefficients[a]						
	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Co-linearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	9.017	2.483		3.631	.00		
W.AREA	24.456	2.574	.568	9.501	.00	.631	1.585
TEMP	-.369	.078	-.233	-4.702	.00	.920	1.087
DRV.SKILL	14.722	2.119	.402	6.948	.00	.674	1.485
WK.CON	-2.995	.665	-.251	-4.505	.00	.727	1.375

a. Dependent Variable: PR

Two other activities which are used for scheduling the highway project in Mashhad are sub-base and base. For these two activities two average production rates are used in order to do the scheduling of the projects. The average production rates of these two activities are gained by the daily reports of the project and the comments of the highway construction projects experts.

6. PRODUCTION BASED SCHEDULER (PBS)

For scheduling the highway project with LSMvpr we need a software package. To reach this goal a package has been presented by the use of MATLAB program. The offered package is called Production Based Scheduler (PBS). The package presented by the author is specifically used for scheduling linear and repetitive projects.

6.1. PBS input

In the software application environment at first user input the data which are related to the size of the working window in the Parameter Configuration section. In this part the amount of the distance and time is entered in the distance intervals tab and time intervals tab. In this research the size of the working window is considered as 1 day and 10 meters because the daily production rates of the embankment activity (daily embankment activity productivity) has been used.

In the tab of Num of Days the zero is entered as default. If this parameter changes the output of the program will be a time location diagram which shows the result of the scheduling up to the preferred day.

The distance window and time window tabs are determining the scale of the output diagrams of the project. These parameters are used in cases which we have huge amount of data therefore the scale of the diagram is needed to be changed in order to understand the output of the scheduling easily. The input parameters are shown in Figure 4.

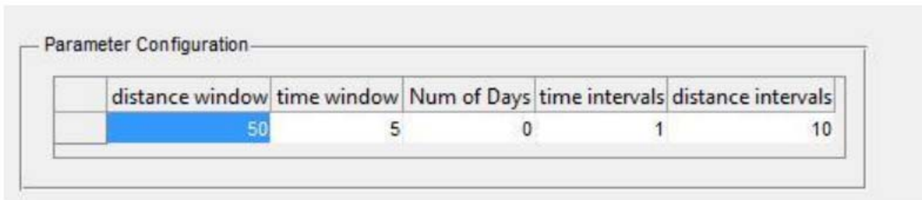

Figure 4. Parameters configuration

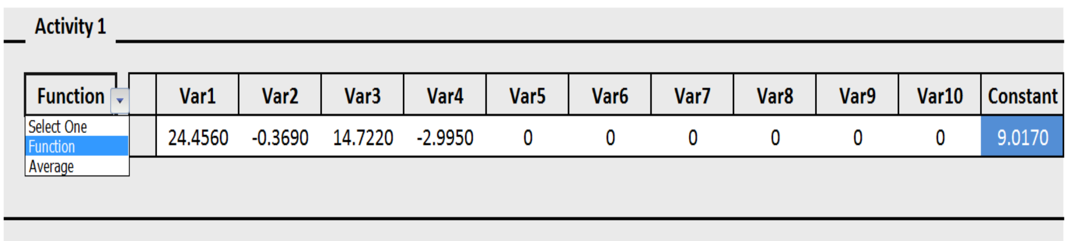

Figure 5. Production data input tab in PBS

The software is presented for scheduling the highway construction projects with maximum 5 activities which are having the repetitive behavior during the project. As shown in Figure 5 for each of the activities three phases are considered for inputting the production data. In the first phase when the user chooses the select one situation from the slide tab the activity is automatically omitted from the list of the activities. In the second situation for determining an equation for the daily production rate of the activity the function mode is chosen from the slide tab. After choosing this mode the section which is related to the independent variables is activated. In this section the user can manually input the coefficients of each of the variables (up to 10 variables have been defined) plus the constant rate of the equation. The daily production equation can be defined by the highway construction project experts depend on the condition of the project but in this paper the equation has been derived from the output of the multiple regression analysis which is done by the spss11 software.

For the third situation user can chooses the average mode from the slide tab in order to input an average rate of production for the activity. In this situation the section which is related to the variables automatically deactivated but the user has to input a number as an average production rate of the activity. For determining the time buffer between the activities in the lead section the user can manually enter the desired time buffer between the two sequential activities with considering the sequential process between the activities (Figure 6). Finally by pressing the plot button the output of the linear scheduling is presented as a form of a time-location diagram.

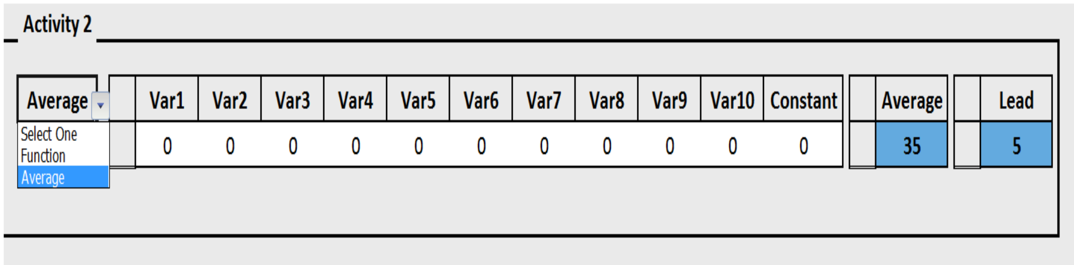

Figure 6. Average production rate input in PBS

6.2. Model validation

The developed model actually is a basis for predicting the highway projects duration with the use of LSMvpr. For validating the model data of a highway project in the city of Mashhad in Iran has been used. The daily production rate equation has been derived from the data of the103 daily reports of the project. The production rate equation for the embankment activity has been derived from the multiple regression analysis which has performed in the spss11 software.

The model validation has been performed by the use of recommended software package (PBS). Three main activities have been considered for the validation which are: embankment, sub-base and base. For the embankment activity an equation has been presented based on the daily reports of a highway construction project in Mashhad. For the sub-base and base activities two average rates of the production rates from the actual data of the project has been derived. For the sub-base and base activities the average rates of the production rates are respectively considered as 35 and 30 meters per day.

Eventually the LSMvpr is used for scheduling the highway project in order to predict the time duration of the 2250 meters of the remaining path of the highway. After inputting the data related to the production rate the user has to run the software by pressing the plot button and in Figure 7 the output of the project is presented as a time- location diagram for predicting the time duration of the project.

As it is shown in Figure 7 the size of the rectangles in the diagram is considered as 10 days and 100 meters but the size of working windows is 1 day and 10 meters. Based on the data the needed time for completing the construction of the 2250 meters of the highway project is estimated about 125 working days. Based on the diagram for completing the 1000 meters of the project 82 working days is needed and also for the executing the embankment activity of the first 1000 meters of the project 39 working days is estimated. But based on the actual progress of the project for the 1000 meters of the path of the highway is done in 96 working days and the embankment operation of the 1000 meters of the project is done in 42 days. By comparing the actual work progress and the predicted values for the time duration of the project, it is recognized that the recommended model and software have an acceptable rate of accuracy in scheduling highway construction projects. Table 5 presents the comparison between the actual results and predicted results of scheduling the sample highway construction project.

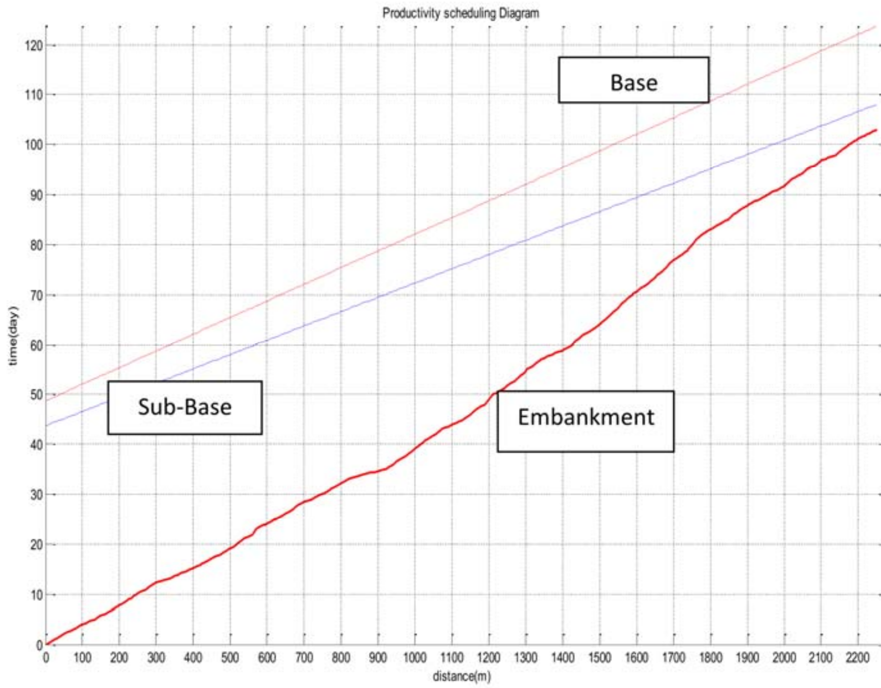

Figure 7. The output of the PBS for scheduling a sample highway construction project

Table 5: The comparison between the actual progress and software output

	Deviation(%)	Actual Project Progress	Software Output
Completion Time (1000 meters of the project)	14.58%	96days	82days
Embankment Activity Completion Time (1000 meters of the project)	7.14%	42days	39days

7. CONCLUSIONS

One of the most important information in construction projects is the ability to predict the time of the completion of the project. Some of the construction projects have the repetitive behavior during the project this kind of projects are included two major type of repetition of the activities, project with repetitive activities in the horizontal alignment and vertical alignment. The important factor in time estimation of these projects is the production rates of the activities. Linear scheduling methods are recommended for scheduling these projects and one of the best linear scheduling methods is LSMvpr. In this paper the method has been executed on highway projects. Three activities are used for scheduling the highway construction project. The embankment activity has chosen to be the leading activity and the production calculation has been done on this activity in order to gain an equation for predicting the production rates of this activity. The calculation has been done by using the multiple regression analysis and with the help of statistical software which is called spss11. For the other activities two average production rates have been presented based on the as-built data. Because of the huge amount of calculation a recommended software package has been presented by coding in the MATLAB software. Finally based on the data of a highway construction project in the city of Mashhad in Iran a model validation has done and the results have been compared to the actual work progress and at last it is understood that the model has an acceptable output in scheduling the highway construction projects.

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