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A STUDY OF CONCEPTUAL FRAMEWORK ON LINEAR CONSTRUCTION PROJECTS

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ABSTRACT

The effect of production rates of linear activities in determining road project durations has been opened as an avenue for research. Application of simulation in road project scheduling has been probed by utilizing the probability distribution of activity durations in road projects. The probable production rates of a standard set of linear activities normally executed in road projects have been arrived with the help of a simulation model using the Extend 5 software. The simulation results thus obtained have indicated a wide range in production rate values as the probability distribution of activity durations was found to be based on various types of road stretches and several factors such as land acquisition and related issues. A typical clearing and grubbing activity was expected to be in the range of 1.3 days/km to 26.9 days/km. Although statistical analysis for goodness of fit with chi-square test for data obtained from several road stretches was satisfactory, the production rates were not suitable for road project time estimates due to its wide variation. As durations of projects due to land acquisition related issues were indefinite in certain cases, an analysis of predictable durations in road projects was felt necessary so as to reach consensus on production rates and gauge the role of constructors more specifically on project durations.The production based LSM developed in this work is restricted to analysis of single sections of road projects. For application in large highway projects where linear construction is undertaken simultaneously at various locations as seen in KTRP, the production-based scheduling method (PBSM) has been included as a comprehensive approach in highway project scheduling. The objective of constructors to complete road projects with minimum delays

is well supported with the PBSM. The model also caters to the variability of production during the course of the project and is sensitive to relevant inputs such as production, progress phases, work breaks etc.

KEYWORDS: Linear Construction Projects, road projects, linear activities, production-based scheduling method

INTRODUCTION

This study will briefly present basic knowledge and concepts in the road planning and construction domain which is the domain that this thesis is based on. First road construction is presented. Then Energy consumption and emissions of vehicles are examined. Finally, some different management methods of road construction are presented.

PLANNING AND CONSTRUCTION OF ROADS

Construction of new roads requires substantial preparation and planning. In the Swedish planning process of roads, the first stage in the process is the idea study where opportunities, needs or inadequacies are observed.

This is not a formal stage but a necessity for constructing new roads. In this stage however it's far from certain that a road will be realized.

The first stage in the Swedish planning process of roads is the idea study. In this stage an overall analysis of inadequacies in the road network is made and possible solutions are identified.

The Swedish Road Administration applies the so called four step principle which is a way of ranking different solutions to the observed inadequacies. The four-step principle is formulated as follows:

1. Rethink

The first step is to consider measures that affect the transportation needs and forms of transportation.

2. Optimize

If that doesn't solve the inadequacies the next step is to consider measures for a more efficient usage of the existing infrastructure.

3. Renovate

If needed, in the third step limited renovations and expansions in the existing infrastructure are made.

4. Construct

If the needs aren't satisfied with the first 3 steps the 4th step is applied. That means constructing a new road or major renovations.

In the Initial study (Förstudie) some expected environmental impacts are observed and unrealistic design alternatives are canceled for further study. If the Swedish Transport Administration in this stage cannot choose one road corridor or if the project needs to be tried for permission from the government of Sweden a Road investigation (Vägutredning) has to be done. Otherwise, that stage can be skipped and the Road plan (Arbetsplan) is the next step.

The purpose of the Road investigation is to more deeply study and assess the different road corridors so that one of them can be chosen. In this stage an environmental impact assessment is made if the project is expected to cause considerable impacts on the environment. When one alternative corridor has been chosen the government needs to give permission for that alternative in order to advance to the next stage.

The Road plan is the next stage where the Swedish traffic administration decides on the final road area within the chosen corridor. In this stage affected individuals, municipalities, organizations and authorities are consulted and appeals can be made. If an environmental impact assessment has been made it has to be approved by the county administrative board in this stage. Once the plan has been validated there is nothing that can formally stop the construction of the road.

The next stage is to produce the Design documents which is the last step of the planning stage. In the Design documents technical design of the road is presented. It has to be compatible with the Road plan and only insignificant deviations can be accepted. If significant deviations have to be made then the Road plan has to be adjusted and validated again.

As the construction phase starts the first work task usually involves removing objects that are not going to be part of the road. This often includes vegetation such as trees and bushes, and sometimes manmade objects such as barns, houses or fences.

Then usually the construction of the embankment can begin. The embankment is also known as the subgrade and consists of naturally occurring material or imported fill material on where the pavement of the road is built. The subgrade work usually involves substantial mass movements.

When concepts like cut and fill and earthworks are mentioned it usually refers to the construction of the subgrade but sometimes also includes some layers above. The materials in the subgrade need to meet some quality standards. For example, its content of organic material needs to be low and the size of the rocks must not exceed 2/3 of the thickness of the subgrade.

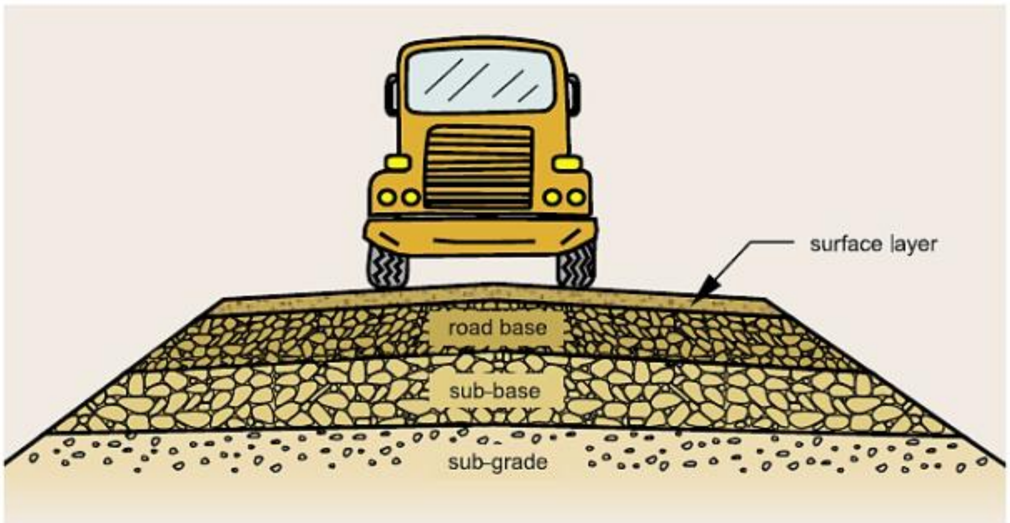

Figure 1: The principal structure of the road

If there is a shortage of masses a nearby borrow pit may be needed. This means using material from outside of the road line. Other alternatives might be to adjust the road line by lowering it.

Excess materials can be used for a number of different usages. For example, by replacing noise barriers with noise barrier earth berms or construct new earth berms where it previously hadn't been planned. The road line can also be adjusted by raising it to accommodate more masses. Another usage could be to sell the material to other projects.

Sometimes the road line is designed to go through bedrock. This requires what is called rock cutting and often involves both drilling and blasting. This work must be done to a level slightly below the top of the subgrade. The occasional pockets formed on top of the bedrock needs to be drained into the side ditches to avoid water from collecting in the subgrade which might have a destabilizing effect.

The subgrade needs to be compacted with a roller to further reduce the risk of water collecting inside of it. Sometimes it might be necessary to use materials that can withstand frost heaving in the subgrade.

On top of the embankment the pavement is built. The pavement consists of a number of different layers with varying thicknesses depending on the planned load bearing capacity of the road and the risk of frost heaving and settlements for instance. The bottom layer in the pavement is called the sub base and usually consists of crushed rock. Sometimes a protective layer is placed between the subgrade and the sub base to keep the materials from mixing but also to minimize frost heaving.

The next layer is the base course which sometimes consists of a granular layer and a stabilized layer.

To stabilize a layer usually asphalt or emulsion I used. The top layer is called the surface layer and most often consists of hot mix asphalt or cold mix asphalt. The difference is merely the temperature of which they are produced in. Roughly 95% of the surface layer consists of crushed aggregates.

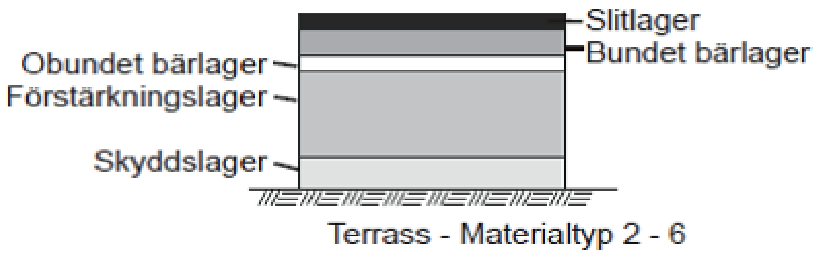

Figure 2: The basic layers of the pavement. From the top: surface layer, stabilized base course, granular base course, subbase, protective layer, subgrade

Earthworks

Earthworks in road construction is the process of forming, moving and processing earth or rock to desired needs through for example cutting, filling and usually some extensive mass hauling. The reason that earthworks often become extensive is because the ground conditions rarely are good enough to meet the requirements of roads. In other words, the ground is most often too uneven and not solid enough to accommodate a road without extensive earthworks. Cutting is the process of taking excess masses and filling it in places where there is a shortage of masses. Roads are usually planned to achieve what is called a mass balance. That means that the volume of cut masses equals that of the fill masses.

Not all masses are suited for being used even in the subgrade of the road. For example, masses with a high content of organic material are better to use as noise barrier earth berms or as surface material on the side slopes. However, some amounts of organic rich masses could be used in the lower parts of the subgrade.

Efficient earthworks include measures for minimizing the mass hauls and the mass volumes for instance. Minimizing mass hauls can be done with the help of some mass haul optimization software.

Minimizing the mass volumes themselves can be done through adjusting the road line profile and plan, without risking that the road doesn't meet the required technical standards.

During earthworks the masses take on different states depending on if they're in their natural state in the ground, loaded onto an articulated hauler for instance, or filled. The different states cause the masses to take on different volumes depending on the fact that masses get loosened up when they're excavated and denser when they're compacted. Furthermore, these states consist of theoretical states and real states. The theoretical state is the needed volume or calculated volume of material in that particular state based on design documents. The real state is the measured volume of a particular material needed for producing according to the design documents.

ENERGY CONSUMPTION AND EMISSIONS

Emissions from internal combustion engines are considered as major health- and environmental problems. Perhaps the biggest problem of the internal combustion engines is its contribution to global warming through the greenhouse effect. The emissions cause a long series of other problems though such as acidification and respiratory problems due to emissions of particulate matter (Haupt& Nord, 2008).

The connection between an internal combustion engine's fuel consumption and its exhausts of greenhouse gases is almost linear. The connection with respect to other emissions is more dependent on the laws and regulations that were in effect when the machine or vehicle was built.

There was for example a law passed that targeted emissions and noise from mobile machinery in 1999.

This is only part of the truth, it turns out that there are many factors affecting the emissions and fuel consumption of internal combustion engines. Frey and Kim (2005) categorize these factors into vehicle characteristics, vehicle activity patterns, ambient conditions, fuel properties and related factors. Vehicle characteristics include for example engine design, its weight and load. Engines with a higher rated power are generally slightly better at translating fuel into usable energy. This means that engines with a higher rated power can do more work per fuel consumed than engines with a lower rated power. This can for example be seen in the specific fuel consumption.

The activity pattern of a vehicle or machine affects both the emissions and the fuel consumption. Changes in a diesel engine's load will affect the torque of the engine which in turn affects the fuel consumption and emissions. The engine's speed and acceleration are two other aspects that affect emissions and fuel consumption but cannot explain the variations in these aspects either combined or on their own Ambient conditions that affect the fuel use and emissions involve outside temperature and humidity.

It's been shown that higher combustion temperatures in the engine cause higher emissions of NOx. The connection between the outdoor temperature and the combustion temperature is rather slim. One study shows that measurements of the air temperature in the air intake turn out to be relatively constant even though outdoor temperatures vary. This implies that the air is preheated before entering the cylinder. The humidity of the air is believed to have some effect on NOx emissions but the connections are not entirely understood.

PROJECT MANAGEMENT IN ROAD CONSTRUCTION

While the basic activities and aspects of road construction have been described previously there is along range of approaches and methods to optimize the construction. Optimizing can be done from several perspectives such as minimizing costs, material use, energy consumption, emissions or time of construction, which often equals to lower costs. Quite often these perspectives are related, meaning that changes in one measure will mean changes in the others.

Some of the methods used to optimize road constructions involve scheduling methods, mass haul optimization methods, the use of alternative materials and machine control to name a few.

Scheduling methods

Construction in projects such as high-rise buildings, multi-unit housing, highways, railroads and pipelines follow a repetitive and linear work progress. This looks somewhat like an assembly line work process where production happens with a pace or is of a continuous character.

This type of construction is called a linear construction project (Liu & Wang, 2012).

This differs from non-linear construction projects such as buildings and industrial facilities which are dominated by non-repetitive work activities. Some common scheduling techniques such as the Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM), have shown to be inappropriate for linear projects. Instead, there have been several scheduling techniques developed in order to handle the linear projects more efficiently such as:

- Line-of-balance (LOB)
- Vertical Production Method (VPM)
- Line Scheduling Method (LSM)
- Repetitive Scheduling Method (RSM)

Critical path method

Perhaps the most common method of planning and scheduling is the critical path method (CPM). CPM schedules are mainly used in projects to show duration and sequence of activities, milestones and criticality of activities. The CPM method shows activities and their precedence relationship to other activities. The algorithm of CPM produces the sequence of activities (path) that gives the shortest duration time of the project of all possible paths (Akbas, 2004).

The CPM planning process consists of the following six steps:

1. Define all significant activities of the project. Only have one start and one finish event defined.
2. Define the relationship between the activities. Does one activity precede or succeed another activity?
3. Draw a CPM network where all activities are connected. Represent each activity with an arrow and an event as a small circle with a unique event number.
4. Assign each activity with the time needed to complete the activity.
5. Calculate the “critical path”, the longest path through the network in terms of time.
6. Use the CPM network to help plan, schedule and monitor the progress of the project.

RISK MATURITY EVALUATION FOR CONSTRUCTION ORGANIZATIONS

This section is a marginally modified version of “A Fuzzy-Based Decision Support Model for Risk Maturity Evaluation of Construction Organizations” published in the journal of Algorithms and has been reproduced here. Risk management in the construction industry has received considerable attention from researchers and industry professionals over the last four decades. The processes of risk management have been widely studied and documented in several international risk management standards and guidelines. Although each standard utilizes a different vocabulary to describe the processes, they mostly follow the same pattern. For instance, the recent classification of risk management processes based on some major international standards including the Project Management Institute (PMI 2017), the International Organization for Standardization (ISO 2009), the Association for the Advancement of Cost Engineering International (AACEI 2013) and the Institute of Risk Management (IRM 2002).

The literature reveals that considerable work has been carried out on risk identification, analysis, responses and monitoring, but far less on risk management planning and risk response implementation. Planning for risk management is the first process in a risk management program and it defines the scope of the risk management as well as the appropriate approaches, tools and responsibilities. In order to increase the efficiency and effectiveness of this process, a risk maturity evaluation study should be conducted to identify the performance level of the organization in its risk management program. Risk maturity provides a measurable tool that shows the degree of formality and progress in the application of the risk management processes according to a set of attributes. It is an iterative process with a dynamic nature which must be carried out on a regular basis.

CONCLUSION

A generalised method of scheduling road projects and estimating durations with the production based LSM has been suggested with a flow chart. The ideal time for completing a continuous stretch of a two-lane carriageway for 5km considering 7 activities for pavement formation with a given set of inputs should take 53 days. If the same project is affected by all factors, it should take 75 days. It is to note here that apart from the probable production rates in activities, the buffer distances play a key role in arriving at these durations. In other words, if the buffer distance and the buffer time interval between activities are increased, then the project durations may increase irrespective of high production rates and relatively small time overruns.

For large highway projects consisting of various developments such as new carriageways, bypasses, service roads etc., the PBSM considering total volume of work against time of activities in the project shall be a practical approach to constructors. Durations of projects can be estimated provided work breaks and progress phases are planned and scheduled adopting probable production rates. This has been illustrated with the production and progress analysis of the KTRP which has taken about 733 calendars days for completion of all the activities. The model also helps constructors in deciding overtime working hours for ensuring targeted production as planned between two calendar dates. The duration of the project needs to be attributed to the quantity of work involved with little relevance to the length of the project. Therefore, based on this study, the model incorporating production rates through Delphi provides for a flexible and improved method of scheduling in road projects based on productivity, site practices and conditions, crews and work quantities.Distance-time linear scheduling becomes complex for large highway projects as works are carried out in parallel at the same time in various locations. Therefore, production based scheduling based on quantity of work is recommended for such large projects due to its versatility in handling varying production and work breaks. However, the use of LSM for different stretches separately can only provide additional information which can help in the effective utilisation of resources and enhance overall production.

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