

# LEAN CONSTRUCTION PRINCIPLES IN INFRASTRUCTURE CONSTRUCTION

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## ABSTRACT

The principles of Lean Construction haven't really been adapted to infrastructure construction because there haven't been tools nor need for this. Across the globe the demand for cost effectiveness towards the private sector has risen and private sector in their part have tried to find solutions from the principles of Lean Construction. This way also the contractors have started to contribute in the development of new methods for finding cost effective solutions. Adapting Lean Construction principles in infrastructure construction means minimization of mass haul amounts and distances.

In order to adapt Lean Construction principles to infrastructure construction, projects need to be managed through mass economy point-of-view. Mass economy means cost minimization for both mass handling and mass haul. Decisions for mass handling procedures and mass haul timings and transfers are made in project's mass economy plan. The decisions are made so that costs for these are minimized. Different planning alternatives can also be examined.

To ensure functionality for production control project is divided into independent mass economy areas. These areas help in defining contract boundaries and in production monitoring and control. This way schedule disturbances and their cost effects can be decreased.

To overcome these difficulties a software program has been developed. To help the planner program has linear and genetic optimization algorithms, which try to minimize the costs for resources, mass hauls and schedule. To help the contractor program has production monitoring and control tools, which can be used to predict and control costs and schedule.

## KEY WORDS

Infrastructure construction, mass economy, optimization, construction cost

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## **INTRODUCTION**

DYNARoad2 is a mass haul and schedule planning and control software developed by DSS Ltd (<http://www.dss.fi>). This software has been developed to function as a tool that can be used in implementing some of the Lean Construction Principles in heavy construction. We believe that Lean Construction in heavy construction means the following:

- Minimisation of waste caused by stockpiling.
- Minimisation of waste caused by resource hoarding through efficient work chain planning.
- Minimisation of material flow costs.
- Maximising work flow using the Last Planner technique.
- Enabling sufficient flow of information for all the necessary counterparts.
- Controlling work flow through realised production and predicting the effect that deviations may have on the whole project.

This article will focus on the largest section of infrastructure construction, which is heavy construction. Most of the principles presented above can also be applied to other fields of infrastructure construction. Research concerning Lean Construction principles in other fields is in progress at the moment and the results will be available in the near future.

## **PLANNING HEAVY CONSTRUCTION**

In earthwork planning, most of the uncertainties of building construction have to be taken into account and, in addition to these, the significant uncertainty of the quality of the excavated masses has to be considered. In other words, it is not always known whether the excavated material is good enough to be used in embankments or whether it has to be dumped. On the other hand, an excessively rapid work flow is rarely an issue, because there is almost always ample work space. An industry-specific challenge in planning earthwork is the source-destination relationship between the tasks: if a cut is in progress there must also be a fill for the mass to be hauled to at the same time and rate. The closer to each other the cut and fill are, the lower the cost of the mass haul. Mass haul related costs can constitute up to 50% of the total cost of the project. Minimising these costs is a key issue in heavy construction.

DYNARoad is a tool that can be used in solving all the problems mentioned above. The source data required for planning using this tool are the station specific bill-of-quantities, the unit cost of hauling different types of mass and the unit or the hourly cost of available resources. This data is input to the system via Microsoft Excel files or by hand.

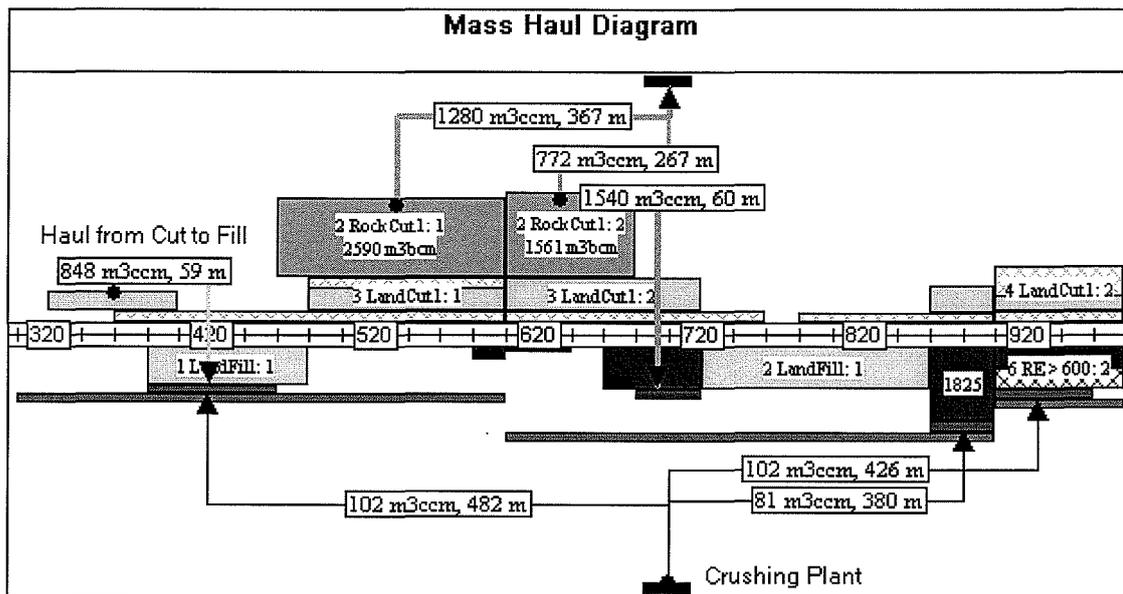


Figure 1: The mass haul plan showing the operation of a crushing plant

DYNARoad2 is compiled of three independent modules: Design, Scheduling and Control. The Design module is a tool for analysing designs through mass haul costs. It works in the following way: First, the station-specific bill of materials is input to the program (this bill of materials is available in most commercial design software). DYNARoad then draws a mass haul diagram and calculates a theoretical mass haul plan with the aid of an optimisation algorithm. This is a graphical presentation of the material flow of the project. The mass haul plan also tells the designers, where the “weak spots” of their plans are. “Weak spots” here mean fills to which the material has to be hauled to over a long distance and cuts that do not have relocation places near by.

The mass haul plan (Figure 1) also shows where the optimal locations of the piling and borrow areas would be. DYNARoad also supports the creation of mass economy areas that may be used in project division. With the help of the plan, designers can also calculate and compare the mass haul costs of different possible designs. Before the creation of this method, designers have not had access to such accurate information at this stage of designing.

The Scheduling module of DYNARoad2 is a tool for creating a mass haul plan to be integrated to the schedule. The schedule and mass haul plan are created taking into account the availability of resources and the production rate, the order of completion of the tasks and the coefficients of the masses in the project. Naturally, all the tasks in a project have successors and predecessors, so the order of completion always stays the same. All tasks are also allocated with certain resources that have specific production rates. These are predefined in the DYNARoad template. The DYNARoad system includes three different schedule and mass haul planning tools: the Gantt chart, the Line of Balance method (Figure 2) (e.g., Yang et al. 2001) and the mass haul diagram.

The planning process used in DYNARoad is a combination of the computer's calculation power and the expertise of the professional planner. First, the planner sets all the necessary schedule and resource-based constraints, such as project duration and milestones. Then DYNARoad starts optimising the costs of the schedule and the mass haul. The costs are calculated as the sum of the hourly (or unit) price of all the resources and the sum of haul costs and the overhead costs determined by the duration of the project. The optimisation

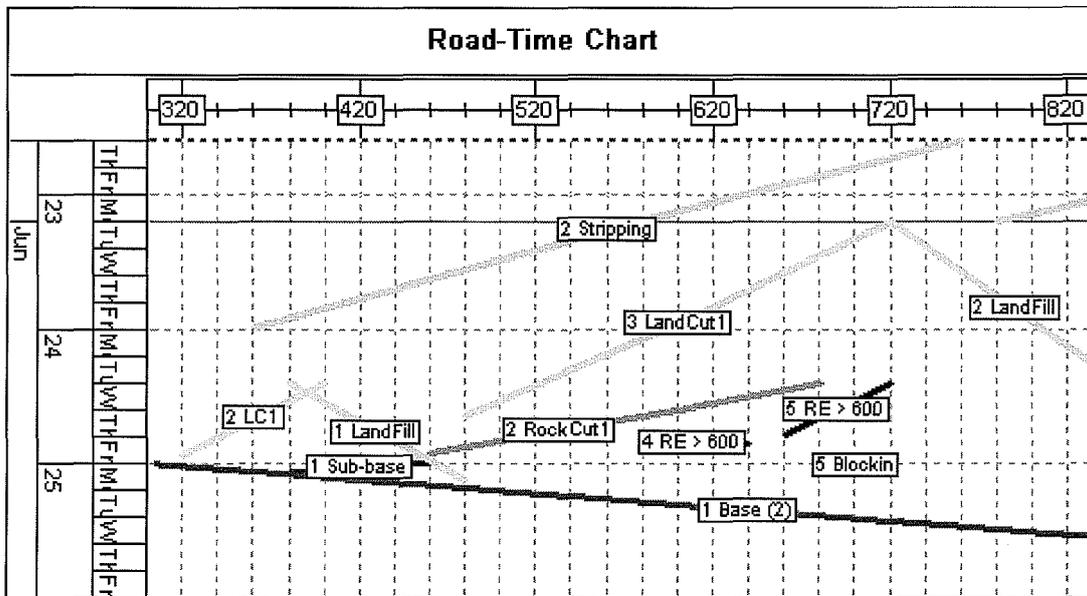


Figure 2: Line-of-Balance planning in road construction

algorithm tries to create the most cost-efficient schedule within the given constraints. Effectively, this means the calculation of a mass haul plan that involves little stockpiling and short haul distances throughout the project.

This optimisation algorithm has proven to be very effective in decreasing waste caused by stockpiling. When the optimisation has progressed for some time (depending on the extent of the project, 10min – 2 hours), the user stops the optimisation and continues creating the schedule manually. These two phases can then be repeated until the user is satisfied with the result. Portions of the schedule and mass haul plan can be locked after a satisfying result has been found. Mass haul planning can also be used when dividing the project into subcontracts. The idea here is to create the subcontracts in such a manner that the tasks included in the different contracts overlap as little as possible. In this way, the subcontractors are much more likely to stay on schedule, since they are independent of the progress of other subcontractors in the area.

This method of planning is particularly effective in keeping resource use under control (Figure 3), because it does not allow the planning of the use of more machines than what are available. All the machines can be identified separately, and their work flows can be planned

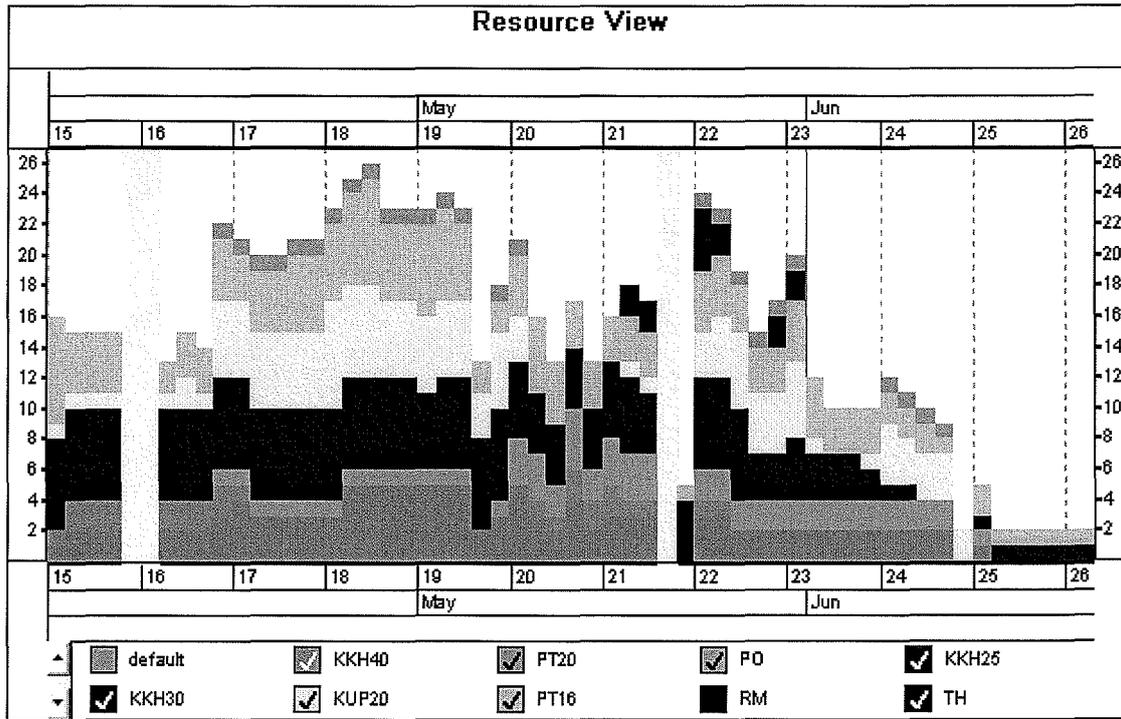


Figure 3: Planned resource amounts as a function of time

individually. This way the machine specific backlogs and buffers can be planned according to the nature of the preceding and succeeding tasks.

DYNARoad generates reports and printable images that can be distributed to all the necessary counterparts either by e-mail or on paper. When all schedule and mass haul related information is stored in and available from one place, the number problems caused by wrong or outdated information is reduced.

## COMPUTER ASSISTED OPTIMISATION IN DYNAROAD2

DYNARoad2 includes two optimisation algorithms that assist the user in finding the most cost-efficient schedule and mass haul alternatives. Because the computer processes planning objectively, the largest benefit brought about by the optimisation process is the elimination of several types of planning flaws caused by human errors,

The first optimisation procedure is a Linear Optimisation Algorithm (LOM). This method is used to generate the theoretically optimal mass haul plan. When the station specific bill of materials is input to DYNARoad2, it is reduced to mass "boxes" that basically have three attributes: The location (X-coordinate) on a road line, the amount of mass (Y-coordinate) and the material type. The material type determines the mass coefficients (e.g. bulking factor) and the suitability of the material. The most complicated task in mass haul planning is the planning of the moving of mass from the cut to the fill. This is however a fairly straightforward linear problem that always has a single unambiguous solution. The function

of the LOM is to find this solution using the information described above and the information on haul cost prices set by the user.

The second optimisation method is used for creating a mass haul plan with a schedule. DYNARoad creates many different schedules that fill all the prerequisites, such as timing and resource use, set by the user, and selects the most cost-efficient schedule for the user. This optimisation process does not end by itself and thus has to be interrupted by the user. As a rule, the more schedules DYNARoad has time to create, the more cost-effective the mass haul plan will be.

The algorithms are designed only to help the planner to create a cost-effective schedule. They cannot create the plans for the user, but can rather help in finding new ways of approaching the problem and fine-tune the plans created by the user. They can also be used to assess the feasibility of plans created without DYNARoad and to identify risks that have previously gone unnoticed.

### CONTROLLING HEAVY CONSTRUCTION

The third module of DYNARoad2 is Control. This module is designed for controlling and monitoring the progress of work at the site. After the schedule and mass haul planning has been finished and the actual work begun, the actuals of the tasks are input to the plans on DYNARoad2. The data needed for this process are the amount and location of the excavated mass and the location where the mass has been taken to. DYNARoad then compares the actual amounts to planned amounts and shows what the actual progress is compared to what was planned. The system also predicts how the work will progress in the future and warns the user if the progress is such that it will cause deviations that will effect cost or cause considerable delay to the project (Figure 4).

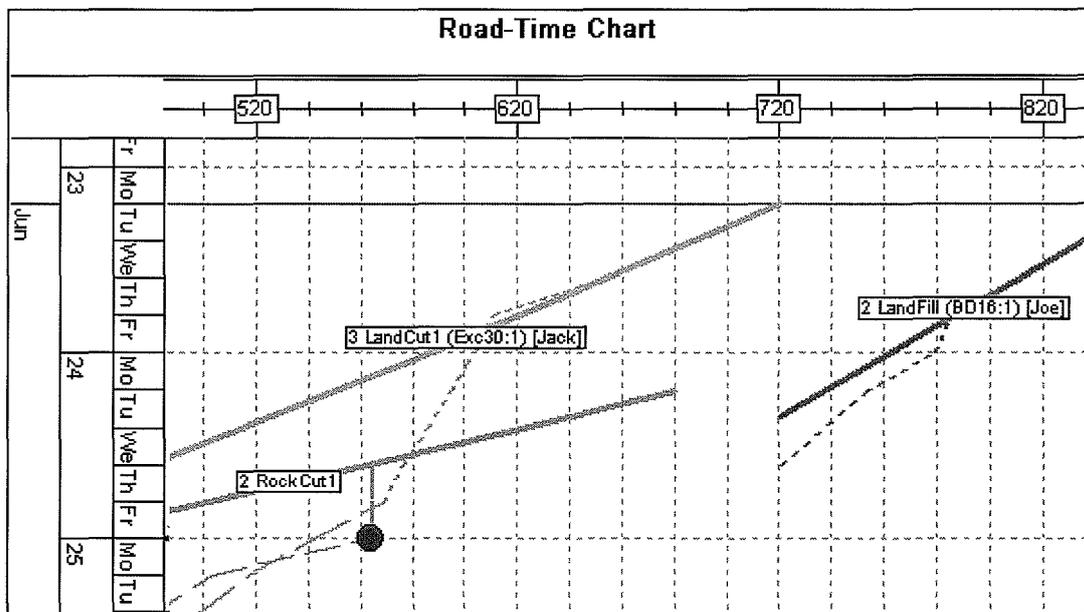


Figure 4: Schedule with actuals (dotted line) and an alarm caused by two intersecting tasks

The control basics of a heavy construction project do not differ significantly from the basics of any other construction project. The most considerable differences are the changes that occur in the amount of cuts and the quality of different cuts. These differences create substantial uncertainty and difficulty in keeping to the original schedule. The control and schedule tools used have to be able to adapt to quick and sometimes radical changes to mass haul plans.

The main objective of schedule control is to identify when and where problems might arise in projects. The consequences of these problems are then determined and the production may be altered so that the schedule can be maintained. A change in one task can lead to changes in several succeeding tasks. Delays also reflect on costs, because delay catch-up always inflicts additional costs.

Non-interrupted flow of information is vital to any construction project, and heavy construction is not an exception. Up-to-date and accurate reports on the project are extremely important to the on-site personnel, the management and the client. The control of the flow of information becomes easier when all the required information is available at the same place, whether it concerns realised tasks or forecast production of the rest of the project. This also makes it possible to optimise the schedule during the implementation of the project.

#### **COMPARING THE REALISED PRODUCTION TO PLANNED PRODUCTION**

A deviation in production takes place when the actual progress of the tasks is different from the planned progress. With the help of the software, the deviation observed is analysed and its effects on production are determined.

Deviations in production primarily result from

- False information on product designs
- Inadequate resource pacing
- Lack of resources
- Lack of materials
- Quality flaws in production

Product design flaws can take place either in regarding material amount or information. Inadequate resource pacing causes overlapping of succeeding tasks and delays in the delivery of resources. Resource design and pacing flaws are the result of inadequate work performance or unfavourable production circumstances. The lack of resources or materials is the result of a machine breakdown, interruptions in shipment or poor procurement. The source of quality flaws can result from the use of an inappropriate production method, the use of inferior materials or inadequate work performance.

Deviation must always be reacted to, whatever the reason. The nature of the corrective procedures is dependent on the total effect of the deviation on production. Deviation primarily influences work arrangements. If correcting these arrangements does not bring production up to schedule, the execution of work has to be re-planned for specific tasks. The main purpose of these corrective procedures is to bring the production up to speed with the

original plan. The main objective is to maintain production according to plan, not the other way around.

## **LEAN CONSTRUCTION IN PRACTISE**

The DYNARoad system is in use in several road construction projects. The system has the following stages: First the initial schedule, mass haul and resource use of the whole project are planned. This facilitates the procuring of subcontractors and assures the planners that the project is feasible with the resources reserved for it.

The second stage is the weekly task planning. This is done on-site as follows: Production schedule and tasks are locked for six weeks in advance. Three weeks in advance, the schedule is checked manually and the resources and the final task order are determined. The schedule of the tasks that begin more than six weeks from the present is constantly being optimised by DYNARoad. This is basically the same as using the Last Planner technique, but this method continuously optimises the plans in order to improve or at least keep up with the original plan.

This method makes it possible to solve several uncertainty-related problems in heavy construction. The schedule varies and changes all the time because cut and fill material amounts and qualities usually differ from what has been initially planned. Even when changes occur, the amounts of cut and fill material can be used effectively because the optimisation of the schedule is an ongoing process. This also makes it possible to compare the realised and planned costs and amounts of materials. This is especially useful when negotiating with the client. The fear of embankment material running out beforehand is unnecessary because the software warns well in advance if this is to happen. This way there is plenty of time to make necessary preparations for procuring additional material.

The method has worked well so far and contractors have been very interested in it and actively taken it to use. With using the method, contractors have been acquainted with the idea of sticking to the original plans. The more old-fashioned contractors have started to use the software because the planning is ultimately done by hand and they do not have to trust the computer blindly. The method also confirms that the project proceeds according to Lean Construction material and resource flow principles. Another Lean Construction principle used, the favouring of pull instead of push, also gets more attention with this active use of this method.

## **CONCLUSIONS**

The DYNARoad 2 system is used by all the major heavy construction contractors and some consultants and researchers in Finland. The largest gain brought about by the system has been achieved in the tender calculation of large road and rail contracts. The system is also used in design control, schedule planning and work progress control of road, rail and harbour construction. The use of DYNARoad 2 has improved the accuracy of the forecasting of risks related to mass suitability by forcing the users to plan their schedule, mass usage, piling and borrowing beforehand more accurately than before. All in all, DYNARoad 2 users have experienced that using the system has assisted them in finding new, more cost-effective and less risky methods of heavy construction.

In addition, DYNARoad 2 and the methods related to using the system have improved the accuracy of some parts of the procurement process. In doing this, it has also revealed some flaws in other parts of the heavy construction process that must be dealt with. For example, currently some construction contracts are drawn up in a way that makes accurate production control and forecasting impossible. Clients are not always aware of what they require. This has caused the designers to create designs that have exceedingly high quality standards in cases where lower standards would be sufficient. Naturally, higher quality often costs more than required.

In practice, the DYNARoad system has increased Last Planner-way-of-thinking in Finnish construction. This means that final and detailed production plans are not made in the tendering phase, but only the rough outlines of the main tasks are decided at that time. The final plans are made on-site in such a way that the original plans are possible to complete. This way, the tendering personnel also learn how to make more feasible, accurate and less risky production plans. The main idea that has to be remembered when using this system is that the production is shifted so that the original plans can be completed, not the other way around.

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