Product Model Based Infrastructure Design

Pekka Montin
Rakennuttajapalaute Rapal Oy, Helsinki, Finland (email: Pekka.montin@rapal.fi)
Tuomas Hörkkö
Viasys Oy, Espoo, Finland (email: Tuomas.horkko@viasys.com)
Tarmo Savolainen
Rakennuttajapalaute Rapal Oy, Helsinki, Finland (email: tarmo.savolainen@rapal.fi)
Risto Nätynki
Viasys Oy, Hannuntie 6, 02360 Espoo, Finland (email: Risto.Natynki@viasys.com)
Juuso Mäkinen
DSS Oy, Helsinki, Finland (email: Juuso.makinen@dss.fi)
Jouko Kankainen
Helsinki University of Technology, Finland (email: Jouko.kankainen@hut.fi)

Abstract

- There is a great need to develop the following sectors of the infrastructure branch:
- The quality of the design process
- The cost management during the design process
- Information management and communication between the different members of the design team

The result and the major cost level of the infrastructure project are defined in the beginning of the project planning and during the design process. Then the scope of the project is defined and the project is designed. Traditionally there have been problems related to the scope and information management. Now three companies have developed together with the Helsinki University of Technology the new product model based infrastructure design process. The process uses the best practise process of the cost engineering and the common product model.

Rakennuttajapalaute Rapal Ltd has developed with 10 major Finnish infrastructure clients (Cities of Helsinki, Espoo, Vantaa, Turku, Tampere, Oulu, Kuopio and Jyväskylä and the Finnish Road and Rail Administrations) the best practise process for scope management costing and cost engineering during the design process. Viasys Ltd is a member of the worldwide Vianova Systems Network and has developed the design software called Novapoint based on the product model. DSS Ltd has developed a program called DYNARoad for optimizing the earthmoving operations. Three companies have developed together a design process based on the product model, which is compatible with the InfraRYL (the new common finnish civil engineering terminology system). The product model based design process contains:

- The project scope setting method for infrastructure client before the design process
    - Systematic project scope definition method for the use of design management

    - The cost estimation based on the scope definition
- The design of the highway based on the previous definitions
- The optimizing of the mass operations in the project
- Cost engineering during the planning process
- The final cost estimate based on the infrastructure building element method
- Quantities of the final result of the design are given to the contractor for further studies

The developed design process with the common product model saves the great amount of resources during the long design process. The result of the design process matches the defined scope better than in traditionally used processes. The cost engineering and the product model can save millions of Euros in the big highway projects.

Keywords: Virtual enterprise, information exchange, information systems, distributed engineering, product model, cost management, earth moving operations, infrastructure management

1. The New Infrastructure Design Process

1.1 Overview

Three commercial companies (Viasys Ltd, Rapal Ltd, DSS Ltd) has collaborated with the Laboratory of Construction Economics and Management of Helsinki University of Technology to create new kind of product model and systematic cost management based infrastructure design process. Traditionally in the infrastructure branch there are many different kinds of data models in use and that makes lots of information waste during the process. The cost management process is not scope oriented and cost engineering in the means of getting economical and quality oriented design solutions compared to the scope is not in the common use. The new infrastructure design process is described in this paper concentrating on the cost management and data transportation.

1.2 Process Relevance

The difference between the reasons of the infrastructure project cost is related to three categories:

- The scope
- The design solutions
- The economical situation on the market

This article concentrates on all three categories in the view of cost management and the data transportation. The main benefits of the new design process are:

- The result of the design process corresponds to the defined scope better

- Data is not wasted during the long process
- The focus of the planning process is getting to the earlier stage of the process than before
- The focus is on the result of the process, not in the process

The infrastructure (highways, streets, railways and big industry yards) investment and maintenance cost in Finland for example were worth of 1,8 billion euros in year 2002. The relevance to the whole society is huge when lots of working hours are saved because of the more complete design process.

2. The Cost Management Process

2.1 The Systematic Scope Definition

The infrastructure is build because of the need to develop or to maintain the basic functions of society. The maintenance of the infrastructure is based on the need to sustain the standard of service of the invested infrastructure network. The change in the functions or the standard of service creates the need to invest more. The needs of the public and the resources in use with the property owner organizations are usually not at the same level. The building process of infrastructure is a long term process including lots of public organizations and ordinary people related to it.

The infrastructure cost management process described in this paper starts with the definition of the needs of the project. The client of the process (usually the public organization) has the responsibility to describe the need, give reasons to the need and take care of the cost management process to reach the target. The needs are modified to targets which are described with end product elements, which are big work breakdown structure components of the project like for example the main way, intersections, bridges and the lightning system (fig 1).

Figure 1: The needs of the project are modified to the targets, which are described as end product elements with the defined scope..

The list of the end product elements creates the framework to the project management based on the systematic and strictly defined project components. The systematic project component division with the end product elements has two purposes:

- To describe the result of the project
- To create the drivers of the project management

Traditionally in the infrastructure branch the process is design and project orientated. In this systematic scope definition the focus of the design process is moving to the earlier stage. There are three benefits of the earlier target orientated scope management:

- The design organisation has clear definition for the scope
- More cost orientated decisions can be made
- The design process can concentrate to the design process and innovations instead of definition of the whole project

2.2 Cost Engineering During the Design Process

The cost management of the project can be based on the estimate theory or on the steering theory. The difference in the two theories becomes concrete in the decision making points (fig2). According to the steering theory the decisions are made so that the cost is under the cost level accepted with the scope.

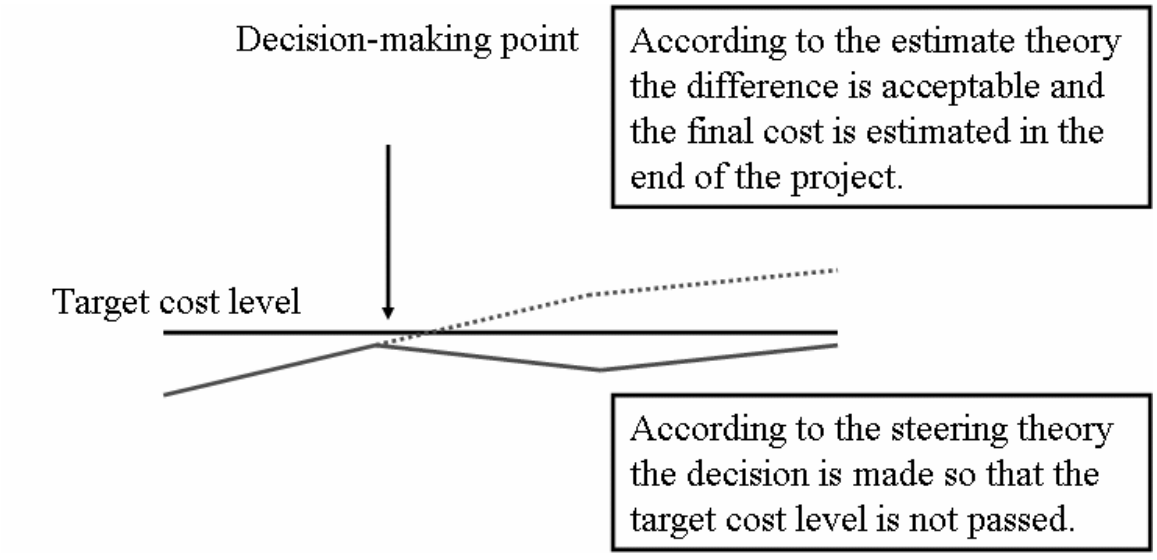

Figure 2: The difference between the estimate and steering theories

Traditionally the cost management is the final action of the design process and the result is more or less declaratory. The cost engineering during the new process is a continuous decision making process. It has three purposes:

- To get comparable prices for different design solutions
- To compare the design solution with the scope
- To estimate the market price for the execution of the project

The cost management during the design process is made with the building element system. The building element is a piece of the product defined in InfraRYL - the new common finnish civil engineering terminology system. The building element consists of the typical production structure in use and the price consists of the prices of resources (work, material, machines). The resource list is updated continuously by the data received from the markets.

2.3 Earth Moving Operation as The Important Part of the Infrastructure Cost and Schedule Management

Mass economy consists of the cost of earthmoving operations and the effect that used design alternatives and the available schedule have on them. These costs are always project specific and that is why it has been difficult and time consuming to estimate them in the past. If this has been done, the results have always has a high degree of uncertainty in them. DSS Ltd has developed a tool called DynaRoad to simplify parts of the process and remove some of the uncertainties related to it. The mass haul planning in DynaRoad is assisted by algorithms that do the all the haul and some of the schedule calculations for the user.

Mass economy calculation yields two major benefits to the design process: the cost of earthmoving operations and the weak spots in the designs that are likely to cause unnecessary costs during construction. The costs and weak spots are discovered by creating a resource based schedule and mass haul plan. This plan can be done in early stages of the project by using information on haul and resources costs that are readily available in the industry. A finished schedule and mass haul plan show an estimate of the project's haul amounts, distances and resource and time requirements that are then combined with other cost calculation information. Analysing the mass haul plans gives the weak spots in the plan. These are for example:

- Structures that have a mass deficit or surplus.
- Structures that have long and large hauls related to them.
- Structures that may cause unnecessary delay to other tasks.

This information can then be taken back to the designers that can check if it possible to alter the plans in some way to get rid of these problems. For example, a mass deficit or surplus could be avoided by changing the vertical alignment of designs or changing the structure type to something that is (or can be made) readily available near by. Structures that cause unnecessary delay to

other tasks could for example be embankments that rely on a cut that can only be done later in the project. This causes a delay on the fill and also all the tasks succeeding the fill.

The use of product models in mass economy calculation speeds the process by eliminating many of the complicated stages that have been previously necessary to get the required data from a design platform to a mass economy calculation system. Instead of using a day to set up a complicated project in the system the required data can now be imported directly from the design platform. After the product model development is complete it will be possible to visualise all the mass economy related information directly in the design software. This will further ease and speed up the work of the designer.

2.4 Benefits of the Systematic Cost Management

The cost management based on the scope management, the active cost engineering and active earth moving operation design gives the systematic approach to the infrastructure cost management. The new process makes different costs comparative and easily managed. The focus of the cost management and the planning of the earth moving operations are moving earlier than traditionally in the process. The more cost oriented design process gives resources to important points of the process and is feasible especially in the tight economic situation when the real cut resources are lower than needed (fig 3).

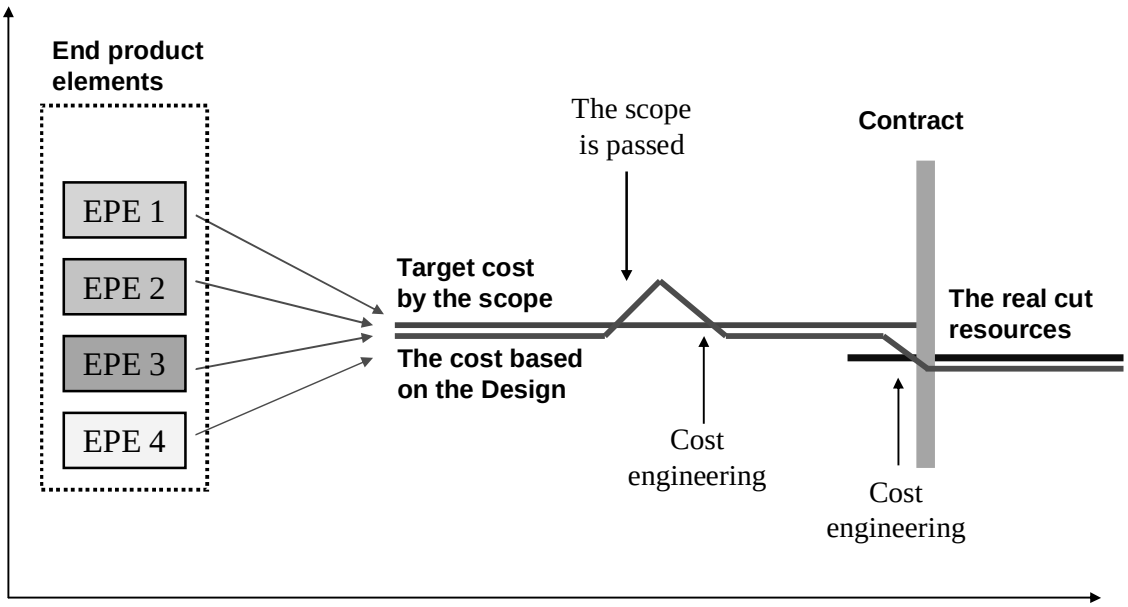

Figure 3: The systematic cost management process in the infrastructure design

3. The Information Process

3.1 The Common Product Model Description

Product model, in general, is an abstract class model describing real life objects and phenomena. Each class describes one type of real-life object. Class description consists in properties and methods. Classes are hierarchically associated with each other and properties and methods are inheritable based on association type. When any class in initialized, it becomes an object signifying a real-life object. During the object initialization, initial values of properties are supplied and initial methods are carried out. Thus, an object always contains some information. Furthermore, each object has a life-cycle and state of existence. With these basic construction blocks and rules, rather complicated real-life models and systems can be reproduced and utilized in computer memory.

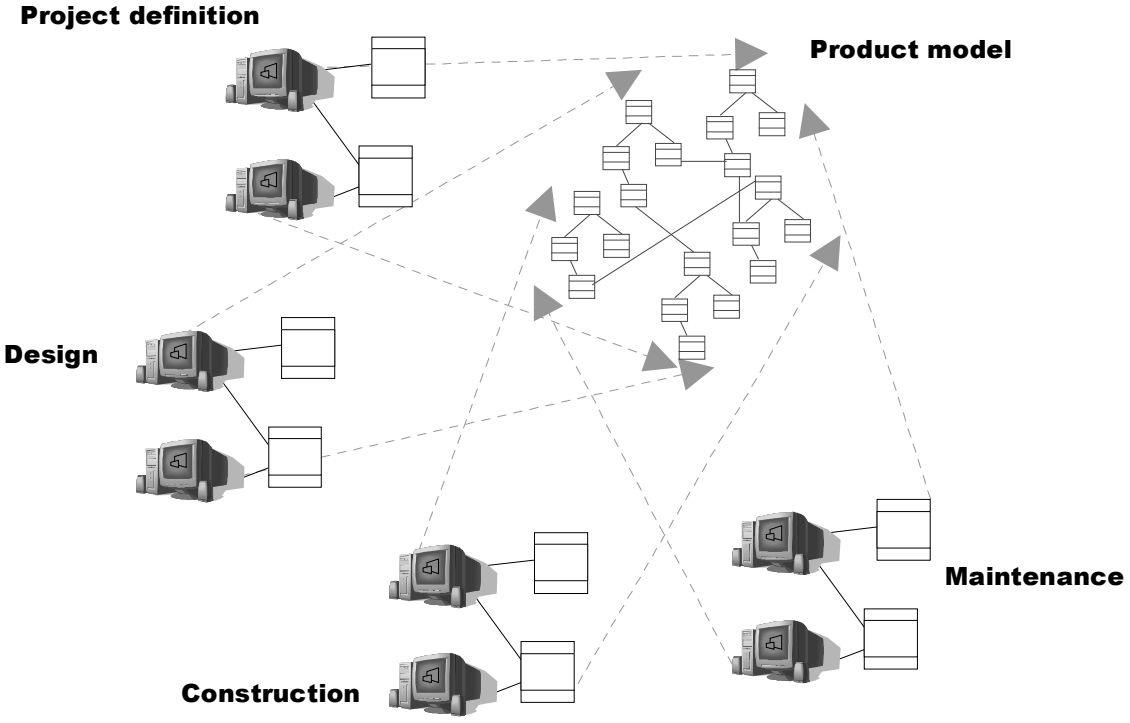

Figure 4: Different views to common product model.

Comprehensive and commonly accepted product model enables communication between different software with minimal or any data-loss. In ideal case the product model is well considered so, that the same product model is utilized in all software used in particular field of expertise. Figure 4, illustrates how the same product model is shared by different software in each phase of a public infrastructure management project. In each phase the product model is updated and developed further to meet the demands and outputs of the project phase at hand.

General methods and tools for holding a product model are, for example, databases, XML-files, text and binary files, in general, and data models in computer memory. Each application is able to read the common product model, or suitable parts of it, into application memory. Depending on the needs of the task at hand, the application view to the product model can be rather different from another application. For example, a cost management application does not need a detailed 3D-model view of a road, when a CAD-system is rather dependent on one.

Software used to produce and maintain the infrastructure design product model, in the concept described in this paper, is Novapoint product family (http://www.novapoint.com). These product model based design and management products are developed to meet the needs of Civil Engineering computing. The individual application modules, sharing the same product model, used in this concept are:

- Novapoint Road Professional
- Novapoint Terrain
- Novapoint Noise
- Novapoint Traffic Signs & Road Markings
- Novapoint Civil Construction & Novapoint SiteTools

3.2 Engineering with Product Model

The product model based infrastructure design process builds up gradually the road model in different project phases. Other relevant models included in infrastructure design process are some basic models, like ground and map models, and some domain models like road, water & sewer, traffic sign and road marking models. Thus, the comprehensive infrastructure design product model consists all of these models associated in strictly ruled ways. Each project phase uses the road model and other relevant models to achieve ones objectives and passes the evolved road model to the next project phase. This data flow in infrastructure design process is illustrated in Figure 5. Process phases are taken from a road design process and they are shortly described in paragraphs after this picture.

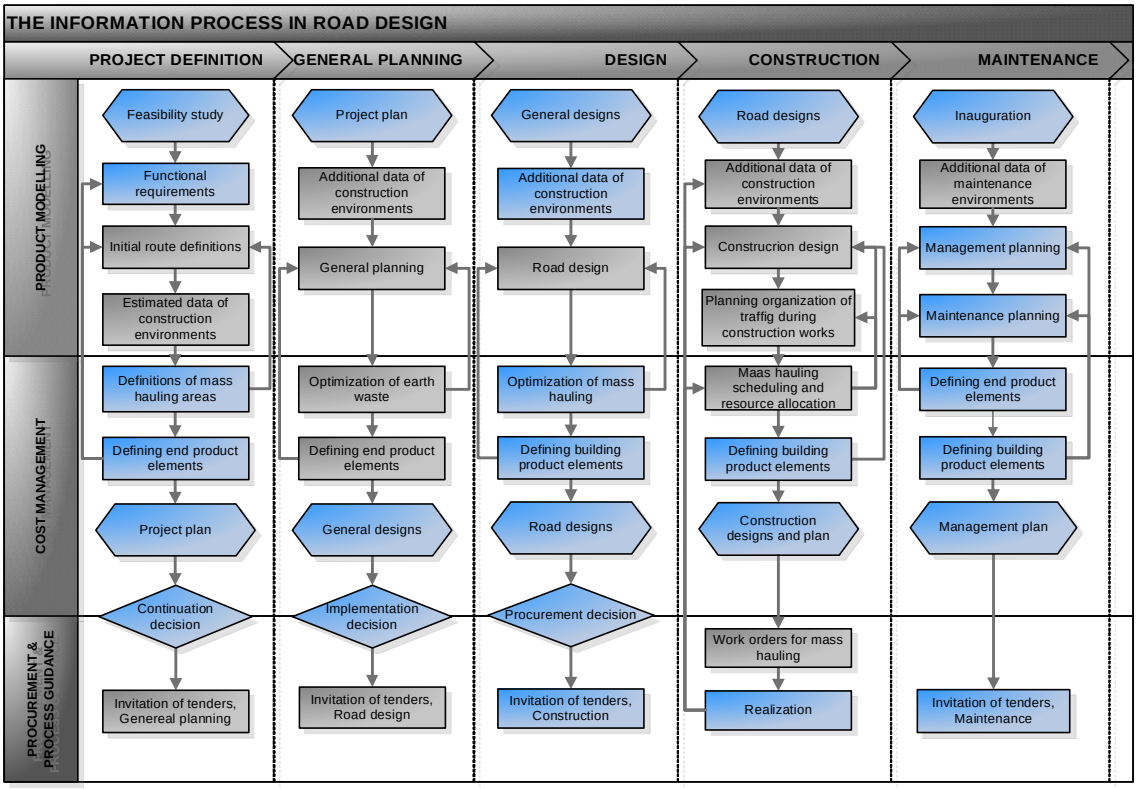

Figure 5: Road design, data flow in the information process.

In *project definition phase*, the product model is initialized against one or more very roughly defined routing alternatives. Systematic project scope definition process generates initial product models and sets of end product elements, with different functional requirements and routing, for comparison. Construction environments conditions and characteristics are roughly estimated in order to gain comprehension of construction difficulty level and costs. Also the first definition of mass hauling areas should be carried out. The risk of miss-approximating the costs, at this phase, are relative to the level of information about construction environment. The systematic project scope definition process outputs are one or more product models with "one-dimensional" parametric road model. The road model, in this phase, lacks any geographical manner of expression. The parameters of the road model set rules for design process in following phases.

In ideal design process the designer receives, after project definition phase, the initial product model in digital form. The designer is able to start more detailed design work immediately. The design work is guided by the product model parameters. The designer is able to deviate from rules set by parameters, but the designer is obligated to have good arguments for any deviation. *General planning* includes also environmental impact evaluation, like noise calculations. Combining all available information the designer is able to produce further developed product model. The road model gains initial alignment and horizontal profile. This enables first trend-setting mass calculations and optimization of mass usage. Basic information gets more specified and the set of end product elements can be decided. After the first ground setting designs, the costs of the construction are quite fixed with some deviation limits. Cost deviation is possible

within the allowed change-limits of alignment and horizontal profile. Also the costs of actual building process elements can vary.

During *road and construction design* phases the product model is developed into very specific level. The product model is completed and the basic information of construction environment is detailed enough for construction planning purposes. Based on completed road model, the designer and the contractor are able to decide the comprehensive list of building process elements. The completed product model is delivered to mass optimization software for analyzing. The mass hauling optimization process is carried out and earth moving operations scheduled with allocated resources. The mass hauling optimization process is iterative in nature. If it becomes obvious, that in order to achieve mass balance, there has to be some design changes, the product model is returned to design software for revision. After this, the economical risks are again estimated based on the amount and accuracy of construction environment information.

The mass hauling schedule becomes the backbone of infrastructure construction project. Surprisingly, in modern road construction projects the mass haul planning can be quite demanding task. In major, road construction projects realize in road sections already in traffic-use. Construction works are not allowed to cause disproportionate blocks of traffic. Based on mass hauling plan, the planning of traffic organization during construction works is carried out. This action requires that the product model enables delivery of mass hauling plan to design software. In design software, the mass hauling plan is analyzed and required temporary structures, traffic signs and markings are designed.

During the construction works, the product model is utilized again. By the use of product model, the contractor is enabled to produce, within design software, daily or weekly work orders with guide maps for mass handling actions. The work order can also be used for reporting the realization of mass hauling works. These reports are inputs for realization analyzing. Based on realization analyzes, the contractor can produce estimates and revision of the construction schedule. Quality control of the infrastructure is carried out by as-built measurements during the construction works. As-built measurements are inputs for analyzing, among other things, realized masses, structure thicknesses and slopes, as well as keeping the agreed tolerances. While analyzing the as-built measurements against the product model, one builds up the product model of realized infrastructure.

3.3 Benefits of the Product Model and the New Design Process

The benefits of product model based design process are quite obvious when one thinks the process trough. One might ask, is there any other intelligent way to do this? All information produced during the process is somehow linked or based to previously produced data. So called rule based designing, managing data in similarly controlled way in all project phases and utilizing common product model in design process enables guidance of the design output and ensures that the functional requirements of the structure are fulfilled. This process approach also brings more economical predictability and fewer risks to infrastructure design and construction. Also, when

the product model is sensitive against inaccurate or faulty basic data, the economical magnitude of possibly realizing risks is known and can be budgeted for.

4. The Benefits of the Process

The benefits of the new product model based design process are:

- The cost management is based on the real defined scope, which is a target for the cost management
- The scope and the design solutions are comparative through the design process
- The data transportation between the systems and the organisations is fluent because of the product model and data is not wasted
- The systematic cost management and data transportation save the amount of the working hours, which were used to routine work
- There is more time to research the alternatives and innovate

5. Conclusions

The infrastructure management is traditionally organised by public organisations. The cost management and the data transportation were developed by the organisations in the branch separately with no collaboration. Now the world has changed. In Finland the public sector is concentrating to the property owner duties. The actual construction and maintenance work is done by the private companies. The property owner has to concentrate to the role of owner in the world of tighter resources. The product model based design process is still developing. The companies are building up a new development project with the University. The results from the piloted process so far indicate that:

- The focus of the design process needs to be in the earlier stage of the process
- The design should be more cost oriented, now many cost effective decisions are passive parts of the process
- The new common nationwide or even more nations covering data model should be developed and taken in the use
  - now too many resources are wasted to routine work
  - now too much data is wasted

References

[1] Haahtela, Y. & Kiiras, J. Rakennuttajan ja suunnittelijan kustannustieto, Finland, 1980

[2] Väylänpidon markkinat Suomessa - Tiivistelmä, (2003) Public website, http://alk.tiehallinto.fi/hankintastrategia/vaylamarkkinat_tiivistelma.pdf

[4] Lean construction principles in infrastructure construction, the public website of IGCL 2004 conference,
http://www.iglc2004.dk/_root/media/13058%5F039%2Dkemppainen%2Dmakinen%2Dseppanen%2Dkankainen%2Dfinal.pdf

[5] Kerzner, H. Project Management – a systems approach to planning, scheduling and controlling, 7th edition, John Wiley & Sons, 2001.

[6] Pilcher, R. Principles of construction management, 3rd edition,McGraw-Hill International (UK), 1992

[7] Project Management Institute Committee. A guide to the project management body of knowledge. Upper Darby, PA 19082 USA: Project Management Institute, 1996.

[8] Angus, R, Gundersen, N, Culliname, T. Planning, Performing, and Conrolling Projects – Principles and Applications, 2nd edtition, Prentice-Hall, inc. Pearson Education, Upper Saddle River, New Jersey, 07457, USA, 2000.