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Optimisation tools for the design of a road project: Recent developments in the European community

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OPTIMISATION TOOLS FOR THE DESIGN OF A ROAD PROJECT

– Recent Developments in the European Community

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ABSTRACT

Present design control and cost management of road construction projects is at an unsatisfying level, which has led to cost overruns, budget failures and expensive design solutions. The design process does not utilise the design control tools such as construction landmass planning, which is crucial for the emergence of road project costs.

The purpose of this article is present a framework which utilises new design control tools for road construction projects. New tools consider a landmass allocation scheme and a project partition-based cost estimation method. The aim of this paper is to evaluate the functionalities of the framework in practice. Furthermore, the paper describes the changes of project parties' actions, which the framework sets.

The studies reported in this article indicate that the founded framework will enable an efficient design solution optimisation. Moreover, project parties will need to integrate their applications and systems if they want the full efforts of the framework. Parallel to this, the building information modelling is a workable platform for the framework and the integration of parties.

Keywords: Computer aided design, Highways and roads, Case study, Cost management.

INTRODUCTION

An infrastructure project is a unique and one-off performance. Requirements, design solutions, initial data and project costs are dissimilar in every project. In many cases, the dissimilarity has affected financials, with cost overruns and budget failures within projects. Exploit of the existing data is impossible because it does not exist. The literature of the transport infrastructure project costs argues that overruns exist in almost 90 per cent of projects (Flyvberg et al., 2003). More than 35 per cent of projects have overrun less than 20 per cent, and more than 25 per cent of projects have overrun from 20 to 40 per cent. Thus, the amount of overruns demonstrate the importance of the development of an infrastructure project cost estimation.

The control elements and the tools of road project designs are insufficient (Manninen, 2009). According to Manninen's study, a construction execution plan does not properly meet the design work. Moreover, the study shows that a cost comparison of the design solutions needs to be systematical, automated and reliable, if cost comparison acts as the design control tool.

Manninen (2009) has represented a framework for the design solution optimisation (DSO) of road projects. The framework is based on design which concerns control elements such as landmass usage planning (LUP) and project partition based cost estimation (PPCE).

Design control elements are produced by various methods and information technology solutions. Thus, it is obvious that integration of the solutions must be without gaps. The literature indicates the potential of the information system integration to increase efficiency, productivity and profitability of projects (Melson and Kronstam 1999). Thus, integration of the design, LUP and PPCE solutions can improve design of the road project towards economical and reasonable judgment.

The framework of the DSO was founded with the constructive approach[3] by the author. The practical relevance and problems of the present road construction project were discovered with 15 theme interviews and a literature review. In general, theory connection of the problem contained areas such as construction management, knowledge management, project management and building information modelling (BIM). The practical function of the framework was proven by workshop and test methods. The theoretical contributions of the results were discussed at the author's dissertation (Manninen, 2009).

This paper represents the framework of the DSO, and summarises the literature and the test mentioned above. Furthermore, the paper discusses the relation of the framework and actions of the road construction parties.

FIGURE 1:

Framework of the design control process

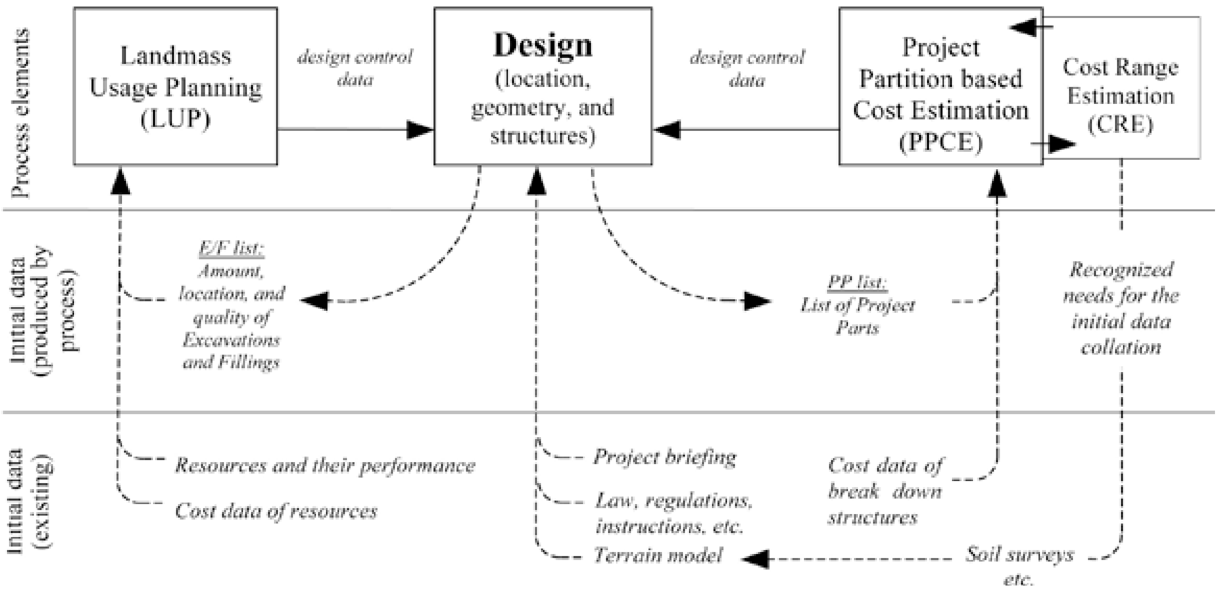
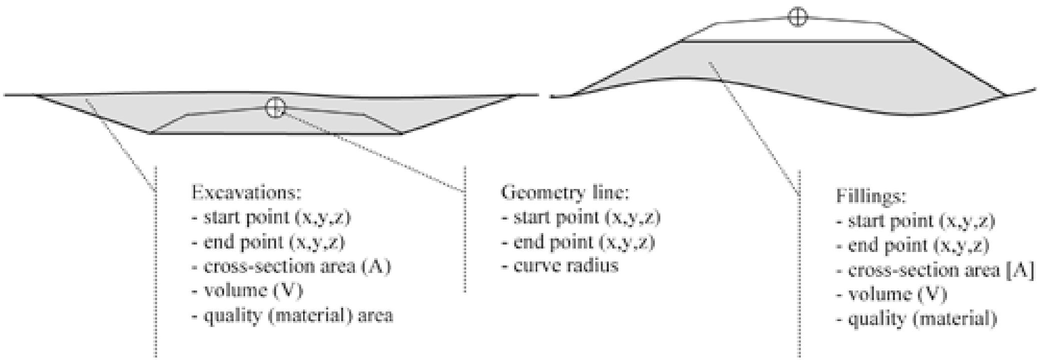


FIGURE 2:

The basic elements of the design in the framework (project part of way)



FRAMEWORK

The founded framework of the design solution optimisation (DSO) in road construction is based on three elements: design, landmass usage planning (LUP) and project partition based cost estimation (PPCE). The framework is shown in Figure 1.

The framework optimises factors such as the project cost, landmass hauling cost and the usage of landmass materials.

DESIGN

The core of the framework is the 3D road design, which sets up the location and geometry of the road and defines fundamental structural solutions. Design's crucial input data, which are not generated by the framework, are project briefing, laws, regulations, instructions and terrain models[4].

A basic element of the design is a geometry line[5] which is fixed to the terrain model according with requirements of speed rates and regulations of road design. Other necessary elements are qualities and quantities of the excavations[6] and fillings. The elements of the design are demonstrated in Figure 2.

In the DSO framework context, the output result of the design is an excavation and filling (E/F) list and a project part (PP) list, which are prerequisites in the LUP and PPCE processes. The E/F list represents locations, amounts, and qualities of the excavation and the fillings. The PP list includes the main project parts. Project parts are divided for necessary and additional parts; necessary parts are a prerequisite for the usability of the road (e.g. way, bridge and tunnel), whereas additional parts are not necessary for road usage (e.g. noise barrier, rest area, and lighting). The DSO process is acceptable if lists are produced automatically and without effort by design.

LANDMASS USAGE PLANNING (LUP)

LUP optimises material usage of road structures and landmass hauling costs. LUP produces plans for mass hauling, a hauling schedule, and plans for resources and material usage. Use of the LUP in the design stage has a remarkable role, as construction solutions are attached to the design through the LUP. The output of the LUP is design control data which is, for example, recommendations for a change of location or level of the way, change of design solution, and the addition or removal of dumping areas.

PROJECT PARTITION BASED COST ESTIMATION (PPCE)

The cost estimation is based on project parts and empirical cost data. The purpose of the PPCE is to produce comparable estimations for the alternative routes of the road, and design solutions. Understanding the costs facilitates decision making and design.

COST RANGE ESTIMATION (CRE)

The PPCD includes cost range estimations (CRE). CRE's define the cost range of the road construction project with the aid of minimum and maximum costs. Cost range includes the estimations of positive case, probable case, and worst case scenarios. The positive case is the lowest cost of the project part; the probable case represents the best understanding of initial data and most the probable cost of the project part; and the worst case represents a situation where by initial data risks are realised and lead to the highest cost of the part.

Cost range is defined for every project part; therefore the total cost range of the project is the sum of each part's cost range. The cost ranges of each part therefore bring to light which parts have the greatest influence on the total cost range of the project. This information helps to allocate initial data collation to the right places[7]. The collected initial data will be included in the terrain model where the data will be linked back to the information about the design.

A project part which has a non-acceptable cost range can be divided into sub parts. The partition of the project parts is justifiable because Lichtenberg (2000) has shown that uncertainty can be managed with a partition method. Thus, if the cost range of the project part is significant, the part can be divided into sub-parts and the cost ranges can be defined for each sub-part.

ITERATIVE OPTIMISATION PROCESS

The DSO process is repetitive. The first step of the process is the non-exact positioning of the road's route. As such, positioning is a definition of the geometric line to the terrain model. The second step of the process is the generation of the E/F and PP lists. Generated lists are used in the third step of the process which is LUP and PPCE. The fourth step of the process is to exploit the results of the LUP and PPCE in design, as control data. The iterative process so far continues that an expected cost reaches, or is less than, an allowable cost, and the total cost range of the project is acceptable.

The allowable cost is a cost that a customer or client is willing and able to pay for a project. The expected cost is defined with PPCE and presents the cost of the project if it is provided at current best practice. The terms of the allowable and expected costs are parallel with studies, which are concerning the target cost process of the construction industry (Ballard, 2006; Ballard, 2007; Pennanen & Ballard, 2008).

The total cost range of the project is determined by the CRE. The cost range has a correlation with the economic risk. Stakeholders of the project have the economic liability, and must compare the cost range with its legibility to carry economic risk. If the cost range is too much for the project's legibility, the identified uncertain initial data needs to be focused.

The process includes data which is transferred between project parties. Challenges which concern data transfer of the building projects can be solved with the BIM (Kiviniemi, 2005; Laitinen, 1998). Consistently, the hypothesis is that BIM will be the best platform to manage information about the framework.

PRACTICAL APPLICATION OF THE FRAMEWORK

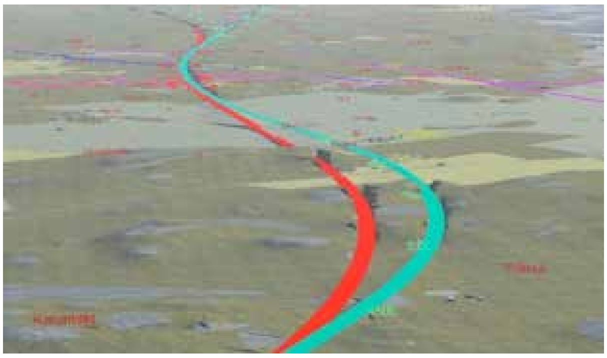
The framework was tested by Finnish Main Road 12 renewal project (Manninen, 2009). The main steps of the testing were the drafting of the preliminary project briefing, setting of the geometric lines and generating the design control data by LUP and PPCE. Furthermore, the testing included the steps involved with the CRE.

The preliminary project briefing was founded on existing data such as the reports, surveys and analyses of the project. The purpose of the briefing was to represent requirements and edge conditions for the project. The main content of the briefing contained a traffic flow forecast, speed requirements of the road, a land development plan and a description of the traffic impacts.

The geometric lines of the road routes were determined according to the preliminary project briefing. Primary data for the route determination were the land development plan, the speed requirement for the road, and the traffic flow forecast. The land development

FIGURE 3:

Geometric lines in the terrain model (Manninen, 2009)



plan affected the location of the road. Parallel to this, the speed requirement affected the geometry of the road, and the traffic forecast affected the numbers of the lanes, the cross-sections of the excavations and the fillings. This was determined by geometric lines which are demonstrated in Figure 3.

E/F and PP lists were generated after the road route was determined. The E/F list was established according to the terrain model and geometric line; the list was founded automatically by the software[8] for a 10 meter division. On the contrary, the PP list was established by hand, because present software did not support project partition.

The LUP was made by software[9] which optimises mass hauling costs and produces a mass hauling plan and schedule. The first mass balance analysis showed that the determined road geometry was strongly surplus and mass hauling costs were significant. With this information, design control data was determined within the testing from which suggestions were made to raise level of the way, increase mass change areas and add dumping areas as noise barriers. Thus, the LUP connected each solution for the preliminary design and construction.

The PPCE was defined for the two route options by cost estimation software[10]. The first option included 14 necessary and four additional project parts. The second option included 12 necessary and four additional project parts. As such, additional parts were the same amount, for both options. The test showed that the total cost of the second option was 4.7 per cent higher than the first option at 15,49 M€. Thus, the control data of the design was in support of the first option, with an economical perspective. The cost structure and project parts of the first option are demonstrated in Table 1.

The CRE captured the cost range for the first route option. The total cost range was 5,12 M€ which is 33.1 per cent of the cost estimation. As such, the total cost range was not acceptable in the test. It was recognised that 84 per cent (4,32 M€) of total cost range was caused by the three project parts. According to this information, the test was given soil survey recommendations for recognised project parts. In addition, recommendations for the sub partition for the two project parts were given. One result of the test was that estimators would site visit during the CRE process, and this would decrease the cost range significantly.

The testing proved that the utilisation of the framework affected the actions of the stakeholders and building processes. Particularly, the framework affected designer actions. By the framework, designers can compare the design solution costs effectively, which helps to find the most economical solutions. Moreover, the LUP and its design control data is a link between the design and construction stages which help the designer to understand how the plans will be achieved.

A client will benefit from the use of the framework on many levels. Use of the preliminary project briefing will ensure that the designer has enough space for innovation and design work. Generally, it is known that innovations can save clients money, and innovations can raise the value of the product. It is noteworthy that the preliminary design stage must include an LUP. The client can demand the use of the LUP in their processes, or include the LUP requirement in their call for offers.

The framework will develop risk management for the project, and the CRE will decrease the cost risk of the project, because risky elements can be recognised within the framework. Recognising the risk elements has a notable role in risk management, as it is a starting point of the management (Cooke and Williams 2007). Furthermore, the LUP decreases scheduling and timing risks within the project. With the LUP, the critical path of the schedule and management can be found in the preliminary design stage.

The framework supports collaboration procurement models such as alliance contracting. The framework is a useful method for connecting the know-how of the client, designers, estimators and contractors.

The test showed that the greatest benefit of the framework can be reached in a BIM environment, where there is a uniform collaboration platform for the stakeholders. Thus, the framework will affect building process and information management. Traditional document-based information flows (Björk 1995) do not

TABLE 1:

Result of the PPCE and CRE

Option #1						Lower limit		Standard		Upper limit		Cost range			
N:o	Code	Type	Name of project part	Qty	Unit	Unit price	Total	Unit price	Total	Unit price	Total	Lower limit	Upper limit	Total range [%]	Total range [€]
Necessary parts															
1	111	Main road	Way 3700-3900	200	m	1 412 €	282 400 €	1 488 €	297 600 €	1 537 €	307 400 €	-5,1 %	3,3 %	8,4 %	25 000 €
2	111	Main road	Way 3900-4500	600	m	1 025 €	615 000 €	1 192 €	715 200 €	1 302 €	781 200 €	-14,0 %	9,2 %	23,2 %	166 200 €
3	111	Main road	Way 4500-4900	400	m	976 €	390 400 €	1 966 €	786 400 €	2 761 €	1 104 400 €	-50,4 %	40,4 %	90,8 %	714 000 €
4	111	Main road	Way 4900-5100	200	m	1 025 €	205 000 €	1 193 €	238 600 €	1 302 €	260 400 €	-14,1 %	9,1 %	23,2 %	55 400 €
5	111	Main road	Way 5100-5800	700	m	3 367 €	2 356 900 €	3 367 €	2 356 900 €	3 367 €	2 356 900 €				- €
6	111	Main road	Way 5800-6000	200	m	1 537 €	307 400 €	2 527 €	505 400 €	3 322 €	664 400 €	-39,2 %	31,5 %	70,6 %	357 000 €
7	111	Main road	Way 6000-6400	400	m	4 967 €	1 986 800 €	4 967 €	1 986 800 €	4 967 €	1 986 800 €				- €
8	111	Main road	Way 6400-7800	1400	m	1 537 €	2 151 800 €	2 449 €	3 428 600 €	2 857 €	3 999 800 €	-37,2 %	16,7 %	53,9 %	1 848 000 €
9	111	Main road	Way 7800-8200	400	m	1 025 €	410 000 €	1 192 €	476 800 €	1 302 €	520 800 €	-14,0 %	9,2 %	23,2 %	110 800 €
10	111	Main road	Way 8200-9000	800	m	3 500 €	2 800 000 €	4 967 €	3 973 600 €	5 700 €	4 560 000 €	-29,5 %	14,8 %	44,3 %	1 760 000 €
11	312	Frame birdge	Bridge	20	m	16 613 €	332 260 €	16 666 €	333 320 €	17 425 €	348 500 €	-0,3 %	4,6 %	4,9 %	16 240 €
12	9013	Other [pcs]	Chamber D 2m	2	pcs	34 953 €	69 906 €	34 953 €	69 906 €	34 953 €	69 906 €				- €
13	611	T-intersection	At-grade intersection	2	pcs	8 702 €	17 404 €	8 702 €	17 404 €	11 284 €	22 568 €		29,7 %	29,7 %	5 164 €
14	611	T-intersection	At-grade intersection	2	pcs	8 702 €	17 404 €	8 702 €	17 404 €	11 284 €	22 568 €		29,7 %	29,7 %	5 164 €
					Total		**11 942 674 €**		**15 203 934 €**		**17 005 642 €**	**-21,5 %**	**11,9 %**	**33,3 %**	**5 062 968 €**
Additional parts															
15	9013	Other [pcs]	Noise barrier (at 7100)	1	pcs	46 603 €	46 603 €	58 254 €	58 254 €	81 556 €	81 556 €	-20,0 %	40,0 %	60,0 %	34 953 €
16	9013	Other [pcs]	Rest Area	1	pcs	34 953 €	34 953 €	34 953 €	34 953 €	34 953 €	34 953 €				- €
17	1081	Road lightning	Lightning (at 8000-9000)	1000	m	60 €	60 000 €	77 €	77 000 €	83 €	83 000 €	-22,1 %	7,8 %	29,9 %	23 000 €
18	9031	Other [pcs]	Environment Art	1	pcs	116 508 €	116 508 €	116 508 €	116 508 €	116 508 €	116 508 €				- €
					Total		**258 064 €**		**286 715 €**		**316 017 €**	**-10,0 %**	**10,2 %**	**20,2 %**	**57 953 €**
					Grand total		**12 200 738 €**		**15 490 649 €**		**17 321 659 €**	**-21,2 %**	**11,8 %**	**33,1 %**	**5 120 921 €**

fill requirements of the framework. In the framework, information which flows inside and between stakeholders must be fast, trustworthy, unambiguous and formal.

The framework stands for information system integration and collaboration of different organisations. Hasselbring (2000) argues that when supporting the intra-organisational business processes, the existing information systems must be integrated. Such integration of organisations concerns layers such as technology, applications and business, and the complete utilisation of the framework requires organisational integration at those layers.

CONCLUSION

This paper argues that information system integration will lead to better design and cost management. As the testing showed, the information system integration is a useful method for the road design process. Nevertheless, this paper is only opening new ways for design; there are many areas of development before complete utilisation of the framework. For example, call of offers will need to move from the lowest design price to the value for money (VfM) aspect.

The framework and BIM utilisation significantly improves present designing process of road projects. The framework provides more information for the designer, and assists with economical decision-making. In addition, the cost comparison between different design solutions is fast and efficient; this provides assistance in finding the most economical design solution.

The LUP increases understanding of the actual mechanics of the project, or in other words, the preliminary design stage is more akin to the construction stage process.

The framework will remarkably develop the risk management of projects. Cost range estimation will help in realising cost risks and allocating initial data collation which has been a huge problem in present processes. This paper does not take a stance on the probability of the cost range, although in future it will be noteworthy to attach a form a mechanism for cost range estimation. The CRE is based on subjective intuition of the cost estimators. Nevertheless, in future research it is important to examine the correlation of this framework and statistical methods. A hypothesis is that the framework with statistical methods will improve present cost range estimations.

The framework is based on a cooperation of information technology solutions. Information flows between solutions needs to be universal, trustworthy and real time. These information requirements are crucial for the function of the framework.

The biggest question in future is how these elements of the framework are best attached to the process? Research and the development of procurement process will be the sure way to answer this question. Procurement processes will have to take into account these elements in the preliminary design stage, not only in the construction stage as is done in present practice.

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ENDNOTES

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3. Constructive approach, please see further information Kasanen et al. 1991
4. Terrain model is 3 dimensional layer model which includes type of terrain. Basic types are residential area, soil, rock, water areas, and exist ways. Terrain model has equal accuracy with maps.
5. In this context road's x,y,z coordination line is known as geometry line
6. In this text, excavation includes also rock blasting.
7. For example exploratory drilling of soil or rock (infrastructure construction).
8. Novapoint software (Vianova Systems Finland Ltd.)
9. DynaRoad software (Dynaroad Ltd.)
10. in|infra.net software (Rapal Ltd.)

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