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RESEARCH ARTICLE

Performance of performance specifications in design-build highway projects

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Abstract

Design-build contracts with performance-based specifications are believed to raise productivity and the innovation rate. Such specifications for highway and bridge contracts may create risks, be too detailed or difficult to verify. The purpose has been to analyse how performance-based requirements are used in Swedish design-build contracts for highway projects. How contractors are encouraged to provide innovative technologies is emphasized. Generic documents from the Swedish Transport Administration for design-build contracts have been studied, and case studies of six design-build contracts with performance-based requirements have been made. Technical specifications for these contracts have been analysed and interviews held with both client and contractor project managers. Results include that it is along the time axis that major obstacles to innovation arise. Before the contractor is able to develop innovative solutions, the initial design plan restricts the highway geometry. During construction, a mix of performance and prescriptive requirement formulations is more of a challenge than clashes between performance requirements. The client may avoid performance language, more so for bridges than road surfaces, because of concerns with efficient maintenance in the future. It is recommended that performance-based specifications

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should be less detailed and that a life cycle view of highway projects should support innovative technologies.

Keywords

Design-build contracting, Performance-based requirements, Highway construction, Maintenance, Sweden.

Introduction

Typical arguments for preferring design-build to design-bid-build contracts for highway projects include shorter project duration through overlapping design and construction, higher productivity and more innovation introduced by contractors (Nyström, Nilsson and Lind, 2016). These benefits associated with design-build are thought to increase if an adequate combination of performance specifications (Sultana, Rahman and Chowdhury, 2013) and warranties is chosen for particular projects. Prescriptive specifications have been identified as one of the obstacles to the adoption of innovative products in road projects, while clients face several obstacles moving to performance-based specifications: knowledge availability, risk, resources and political will (Rose and Manley, 2012). On the other hand, performance-based requirements used in specifications for highway and bridge contracts may suffer from being too detailed or too difficult to verify. Thus, transaction costs may arise from specifications being costly to formulate for the public agency or to interpret at the bid stage; measuring the fulfilment of requirements cannot be too costly, as well as the effort of resolving potential conflicts when interpreting measurement data (Hughes et al., 2006).

Under design-build schemes based on performance specifications, contractor efficiency may be increased not only by innovations but also, and perhaps even more, by the potential for broader choice among existing and known technical solutions. Which effect that will be dominant, from innovation or from selection among a range of alternatives, could be the result of how clients actually formulate and apply performance specifications. Today, there are specialized guidelines for writing and using performance specifications for highway construction projects (Scott et al., 2014; Scott, Konrad and Ferrugat, 2014). An international overview has been published by Stankevich, Quereshi and Queiroz (2009).

Against this background, the purpose of this investigation is to analyse how performance-based requirements are used in Swedish design-build contracts for highway projects. The emphasis is on how contractors are encouraged to provide innovative technologies in this context. While there have been several large-scale surveys comparing design-build and design-bid-build contracts as to their budget and schedule outcomes (Hale et al., 2009; Minchin et al., 2013), the present investigation has its focus on an in-depth analysis of six highway projects, with project managers of both the public client and the contractors being interviewed, combined with a textual analysis of project specifications.

Performance-based requirements

In contrast to detailed prescriptive (execution) specifications, performance-based requirements are oriented towards the function of structures. It is a theoretically attractive proposition that all requirements for structural designs should be formulated in performance terms, as in the axiomatic design framework (Albano and Suh 1992). Axiomatic design is a theory that operates with functional requirements, FRs, and design parameters, DPs (Suh, 1990).

Nevertheless, there is now a number of studies where axiomatic design has been applied to problems in civil and environmental engineering (Marchesi and Matt, 2016), although the relation between clients and contractors as mediated by specifications has not received attention. Essentially, the client would issue FRs and the contractor would identify the relevant DPs. The challenge for the client is to develop a hierarchy of FRs while having imperfect knowledge of DPs. When Suh (1990, p. 36) brings up hierarchies of FRs, he says that it is necessary to alternate between the functional domain and the physical domain when moving to a lower level of FRs. This pendulum movement is inhibited when FRs are formulated as specifications directed towards contractors and are to be interpreted by them. Nevertheless, the Independence Axiom belonging to Axiomatic Design is noteworthy: "Maintain the independence of FRs"; lack of independence of FRs has been seen as a problem by Meacham (2016) in an international study of building regulations. There is sometimes a conflict between performance requirements for energy efficiency in housing and other requirements intended to secure health and safety of occupants. In the case of road projects, it cannot be excluded that there might be similar conflicts between performance requirements.

Two aspects of performance (or functional) requirements appear to be essential as influences on the scope and incentives for innovative technical solutions brought forward by contractors: risks and how the client has developed its hierarchy of requirements.

RISKS

Both clients and contractors are subject to several risks in design-build projects with performance specifications. An early but still useful analysis of factors that determine how much detailed control should be exercised in public design-build requests for proposals was made by Songer and Ibbs (1995), whose focus was on encouraging innovation in the building process. The determining factors were identified as the local economic conditions, in particular demand and supply of construction, the design-build environment (public policy compatibility of specifications that contractors are familiar with, as well as local community design-build experience) and project specific data, such as contract amount, degree of facility specialization and schedule. Although their analysis was orientated not primarily towards highway projects, a number of observations are useful in the context of the present study. They emphasized the need for determining the existence of feasible design options, considering "relative impact, relative economies, local practices, and ability to evaluate".

Evaluation of performance is a crucial matter. Among the categories of risk associated with design-build identified by Patil and Molenaar (2011), three are especially pertinent: limited ability of performance models to predict performance, limited ability of the measurement and sampling to reflect reality [validity!] and warranty-related risks. Obviously, issues of measurability and predictability of how performance will develop over the life cycle of a structure adds complications. As mentioned initially, the client will incur transaction costs from formulating requirements, monitoring their fulfilment and resolving any conflicts originating in ambiguities (Hughes et al., 2006). Bidders and ultimately the selected contractor will face similar costs.

Patil and Molenaar (2011) furthermore indicate risk associated with hybrid specifications, also known as composite or mixed specifications (Loulakis, 2013, p.9), which may restrict innovation or require contractors to assume responsibility for specifications where they have limited control over the design. One reason why a client may wish to restrict contractor choices to precisely specified alternatives or single technical solutions is in the case of components which in time will need replacement (such as future needs for spare parts for bridge railings) or other risks for complicated and costly maintenance procedures (cf. van Dongen, 2016).

Concessions or very long warranty periods (Scott et al., 2011) are expected to provide stronger incentives for concessionaires or contractors to optimized technology choice over the life cycle. Here, the problem is that the economies of scale can be different for new construction of roads (cf. Verhoef and Mohring, 2009) and for their subsequent maintenance and operation, where it is known that road length often, but not always, is associated with lower unit costs (Blom-Hansen, 2003; Wheat, 2017).

Accessible methods for non-destructive testing might not cover all important aspects of performance, however, and the durability of certain materials and combinations of materials is often difficult to predict (Guo, Minchin and Ferrugat, 2005). Gruneberg, Hughes and Ancell (2007) stress the risk that contractors expose themselves to unless innovations have been tested previously, before implementation, also because contractors need to ensure that there will be a cost reduction. At least in countries where performance-based design-build contracts for highway projects have been developed over more than a decade, the range of risks appears smaller than for other industries where output-based contracting is a more recent phenomenon and where less learning has taken place (Hou and Neely, 2018).

HIERARCHIES OF PERFORMANCE REQUIREMENTS

Regardless of which level of detail a client wishes to reach in formulating performance indicators, it is reasonable that they should reflect what Haas et al. (2009) call transportation values, which can be formulated in national transportation policies, as in the Nordic countries. For the purposes of empirical analysis in the present study, we shall rely on the broad view of transportation policies expressed in a Norwegian study (OFV 2009), which lists the values (or domains) of accessibility, trafficability (mobility), reliability, safety, comfort and adaptability to the environment. Whereas some countries have been more hesitant in adopting design-build based on performance requirements, Sweden, Norway and the Netherlands are considered to be among the pioneers and thus have been able to accumulate experiences of this contractual path (FHWA, 2002).

In the Netherlands, the Rijkswaterstaat (an agency under the Ministry of Infrastructure and Water Management) has developed a requirement pyramid where the detailing degree gradually increases when reading the figure from top to bottom (Korteweg 2002). On the highest level of the pyramid, there is only a requirement on location (i.e., from A to B), trafficability (maximum loads, velocity, number of vehicles per hour, number of access hours per year during the service life), safety and environment.

An example of various requirement levels can be based on current experiences of how steel bridges are procured by the Swedish Transport Administration. For steel bridges, the fundamental requirement on access hours during the serviced life is translated in the actual specification document into a detailed execution requirement on the corrosion protection (Figure 1).

Contract specification documents are not always clear and transparent in their presentation of the hierarchy of performance requirements. The Rijkswaterstaat, however, systematically indicates for each performance-based requirement any superior and subordinate requirements, together with the procedure for verifying fulfilment.

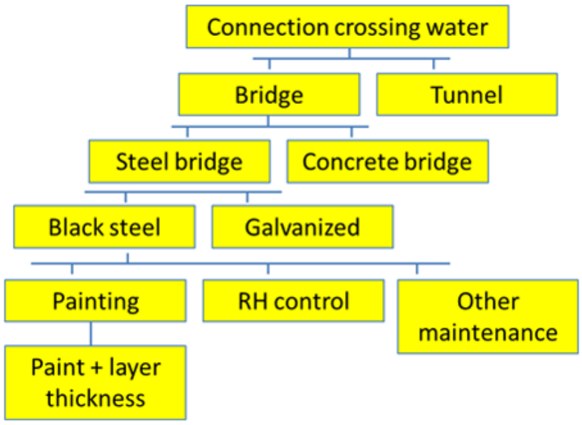

Figure 1 Connections across rivers and other watercourses can be made in several ways; the degree of specification detail increases gradually downwards

If highway design-build contracts with performance specifications are to encourage contractor innovation, or simply contractor choice of applying cost-saving known technologies, requirements should be chosen with the costs of monitoring and dealing with non-compliance in mind. This principle has consequences for how the hierarchy of performance requirements is designed. Each requirement is thought to be associated with a measurement technology and cost. Where to stop the descent towards a higher degree of detail in the hierarchy can be interpreted as a question of the optimal proportion of design by clients in design-build projects (Xia et al., 2013).

While earlier authors (e.g., Kuzyk, Haas and Cockfield, 1991) might use the concept of performance-based specifications as a generic term in opposition to 'recipe' specifications, Chamberlin (1995) distinguished between performance specifications, performance-based specifications and performance-related specifications. The difference between performance specifications and performance-based specifications would be that the former describe how the finished product will perform over time, whereas performance-based refer to a desired level of fundamental technical properties which may be used for predicting performance and can be included in models for calculating performance. Unlike the style of performance-related specifications, these properties are mostly impossible to measure directly at the time of construction. The questions of what is measurable and when it is measurable emerge as crucial, just as the existence of dependable scientific models supporting prediction of how properties will develop over the life cycle of the structure.

Proceeding downwards in the hierarchy of detailed performance requirements is subject to a challenge when the life cycle dimension is introduced, particularly with an increased emphasis on environmental sustainability. It has long been recognized that aesthetic requirements on highways and bridges are difficult or impossible to formulate in terms of performance. More important from a technology viewpoint is the recognized difficulty to translate requirements derived from environmental sustainability goals into performance-based requirements (Bröchner, Ang and Fredriksson, 1999). The reliance on environmental impact assessments as a compulsory element in the Road Design Plan in the Swedish roads planning process (Isaksson, Richardson and Olssen, 2009) leads to harsh restrictions on locational and geometrical changes that can be suggested by a contractor, once the plan has come into force. Similarly, in the US context, Tran and Molenaar (2014) mention the design-build contractor risks arising from environmental conditions and restrictions, including the potential need for reissued permits if design deviates from the original plan.

When relying on performance-related specifications, positive or negative pay adjustments according to quality achieved can be provided by clients as incentives (Chamberlin, 1995). Such incentives, however, can be sources of additional transaction costs. The effect on the contractor propensity to innovate could be favourable, although this has not been investigated sufficiently.

It is conceivable but not obvious that the use of performance specifications may be affected if the choice of a design-build contract is influenced by a wish to accelerate projects, an intention that appears to be more common in the US than for Swedish public clients. If as a consequence the time allotted to geotechnical investigations is shorter than under design-bid-build, contractors are exposed to additional risk (McLain, Gransberg and Loulakis, 2014; Castro-Nova et al., 2018).

In general, and against the background of prior research, it is reasonable to interpret performance-based requirements as requirements that in measurable terms prescribe properties of a building, civil engineering structure or part of those at a given time or the time-dependent change of these properties. The time dimension is important.

Methods and materials

Based on the literature survey, current generic documents produced and used by the Swedish Transport Administration for design-build contracts have been analysed. Case studies of six design-build contracts with performance-based requirements have been made, including an analysis of specification documents and interviews with both client and contractor project managers. The six case studies in Table 1 were selected among candidate projects listed by the Transport Administration, applying four criteria. The project should at least partly have been carried out after the Transport Administration was formed by a merger in 2010, and the project should have been opened for traffic not later than during 2015/16, rather than including unfinished projects with a potential for still unresolved conflicts related to performance issues.

Thirdly, the investigated projects were intended to represent a variety of contractors, and finally, the set of projects should include examples of both new construction and reconstruction. All four contractors were large, each with an annual turnover in excess of MEUR 500. The reason for choosing large contractors is that they are expected to have a higher level of competence; Zhang et al. (2018) hypothesized that a higher degree of contractor competence would strengthen the negative influence of the level of owner-provided design on design innovation, and their analysis of questionnaire responses from Chinese project professionals supported this hypothesis.

In all six studied cases, the Swedish Transport Administration had issued specifications as an "Object Specific Technical Description" (Objektspecifik teknisk beskrivning, OTB). These follow an identical format with the requirements described under three chapter headings: (B) Road traffic, (C) Existing ground, environment and structures as well as temporary structures, (D) Road structures. Chapter D deals with both roads and bridges. For analytical purposes, we have assigned these requirements to six requirement areas defined in the Norwegian study (OFV 2009): (1) Accessibility, (2) Trafficability, (3) Reliability, (4) Safety, (5) Comfort, and (6) Adaptability to the environment.

Separate interviews with both client and contractor project managers were held for each of the six projects. These were telephone interviews with a duration of about one hour and immediately transcribed for analysis. Interviews were semi-structured and followed a guiding scheme with five groups of questions: application areas for performance requirements, effects of performance requirements, bonus and penalty clauses, interpretation issues in requirement fulfilment and finally a question about geotechnical information provided by the client (see Appendix).

Table 1 Analysed design-build highway contracts

Contract sum (MSEK)	Contract period	Type	Total length (km)	Contractor	Project
66	2014-2015/16	C	4.3	Large Danish contractor	Inre Kustvägen, Båstad
233	2009-2011	C	< 5	Large Swedish contractor A	RV 31, Tenhult
230	2009-2010	C	< 5	Large Swedish contractor B	RV 34, St Alby - Glahytt
164	2011-2013	C + R	11.2	Large Swedish government owned contractor	RV 27, Gislaved
100	2014-2015	R	14	Large Swedish contractor B	Road 288, Hov - Alunda
1900	2010-2013	C + R	28	Large Swedish contractor B	RV 50, Motala

Note: SEK 1000 = about EUR 96. C = (new) construction, R = reconstruction. RV = Riksväg = National road; Inre Kustvägen, Interior coastal road.

Participants were able to see draft texts derived from what they had said, and in a few cases suggested alternative formulations to clarify their views. Anonymity was guaranteed.

After the interviews had been completed, a workshop with representatives of major contractors, clients and consultants was held under the auspices of the Swedish Construction Federation. Discussions at this workshop supported the analysis of interview responses.

Results: document analysis

The Object Specific Technical Description (OTB) for the RV 27 project states initially that a road bridge must be "trafficable regarding capacity, durable, stable with sufficient load-carrying capacity, accessible, comfortable." The road bridge has to be designed "for road safety, aesthetically, environmentally correctly." It can be seen that all the six requirement areas are invoked.

Requirements can also be assigned to different levels, from a general to a more specific level, as shown in Fig. 1. As proposed by Chamberlin (1995), we may distinguish between performance specifications and substituting (proxy) performance-based or performance-related specifications. The OFV (2009) Norwegian study provides examples of performance specifications within all its six areas. For Safety (requirement area 4), the requirement reads "Accident frequency < 0.10". On the other hand, the Swedish Transport Administration defines requirements on friction (between vehicle wheel and riding surface) by stipulating a specific value of the friction coefficient. Higher friction reduces the braking distance thus contributing to improved traffic safety. However, in a contract providing more freedom of choice, the contractor would be able to fulfil the fundamental safety requirement in performance terms by other measures, e.g., wider road with more traffic-separated lanes or a traffic control system preventing car drivers from exceeding the speed limit. Evenness is specified as a performance-based requirement on comfort. An uneven riding surface impairs the comfort for both car drivers and passengers, but this is just one of several factors. Lane width, possibilities to overtake slow vehicles, visibility during night traffic, spacing between service areas, and surrounding landscape are examples of other influencing factors.

The Swedish requirements for the road include service life of the various layers, settlement, frost heave, load-carrying capacity, frost slipperiness, friction, evenness and rutting. Only the requirements on service life (20 years for bituminous layers, 40 years for hydraulically bound and unbound layers, and 80 years for strengthening the subgrade) and frost slipperiness ("must not be present") are real performance requirements. All the others are performance-related requirements where measurement methods and limits of the measurement values are stated.

The studied OTBs have shown that while requirements on roads are either formulated as performance specifications or as performance-related, the requirements on road bridges are rarely stated in performance terms but are prescriptive requirements. On one hand, there are requirements stating "vertical clearance above riding surface should be ≥ 4.70 m", on the other hand "edge beam should be designed according to Bro 2004" (Bro 2004 is a previous Swedish bridge code) and "intermediate supports should be designed as circular columns". The specification of vertical clearance above riding surface may be interpreted as a performance requirement, but all prescriptive requirements on bridge members limit the possible solutions considerably. In fact, there are also detailed technical requirements found in the OTBs indirectly prescribing how to produce the concrete, e.g., "When using concrete, visible concrete surfaces should be floated surfaces". Implicitly, this statement eliminates precast concrete since the technology giving floated surfaces is only used in cast-in-place concrete production.

There is thus a contrast between the reliance on highly developed performance criteria for road surfaces and the prominent role of traditional, detailed prescriptive style of specifications for bridges. This can be explained partly by dedicated technologies for bridge operations and maintenance (van Dongen, 2016). As owner, the client may wish to avoid a plethora of components across a large stock of bridges to be maintained.

Results: project manager interviews

There was a consensus among project managers that specifying pavement (surface) conditions in performance terms works well. The load carrying capacity can be expressed as required modulus of elasticity for various strata of the superstructure. On the other hand, rock slope stability requirements were thought to be particularly difficult to formulate, especially if rock quality is described with a low degree of precision.

Relying on performance requirements in projects that include reconstruction (rehabilitation) of existing roads is thought to be more difficult than for new construction, not least when the client describes current drainage conditions. There is a noticeably higher risk of mistakes here.

Considering how contractors assess pavement related risks, the warranty period for road projects must be selected carefully. Two alternatives have been identified: (i) a period that is so short that there is a low probability for replacement need before the end of the period (typically about eight years) and (ii) a period that is so long, twelve years or more, that one or several replacements are anticipated during the period.

Landscape and bridge design requirements are generally seen as difficult to translate into performance specifications. The client may wish to secure a particular design in order to secure an expected impression when a bridge is viewed in its landscape setting, which may reduce the ability of the contractor to use prefabricated components and gain advantages from standardization. A more context adapted style of requirements was suggested by one contractor project manager, implying that higher demands on visual aspects should be formulated for urban areas and especially sensitive parts of the landscape. The phrase "or similar" in specifications was seen as particularly hard to interpret when dealing with aesthetic requirements.

It is probably because contractors are allowed to choose among a greater range of technologies known to them that performance-based requirements are associated with lower cost, shorter project duration and higher quality. There were few examples of innovations in the six case studies. In one project, the contractor project team first explored an innovative simplified technical solution to reduce the number of layers, but top management was not satisfied that the durability risks were fully understood, given a ten-year warranty period, and a more traditional design was retained. From another project that included a twenty-year maintenance period, a number of technology changes were reported: LED lighting, use of dedicated software for mass haul calculations, and standardized bridges. Stone material was chosen differently, and for the bridges in this project, special efforts were made to ensure better insulation and a higher quality of painting. In a couple of cases, an innovative technology was subject to joint client-contractor prior testing.

More than one contractor project manager emphasized that the scope for introducing innovative technologies is restricted by the initial, legally binding road design plan, since it fixes the road profile and the terrain corridor rigidly. If the tolerance for height (elevation) deviations is only ± 0.1 m, the scope for innovative and optimized rebalancing that also could increase environmental sustainability is limited. Two of the earlier projects had been allowed more tolerance, with as was claimed good effects. Related to impacts on the surroundings, it was mentioned that the client should describe drainage conditions as clearly as possible.

Respondents indicated that conflicts between performance-based requirements were rare and unimportant. This should be an advantage, but another interpretation is that this lack of conflicts arises from requirements taking aim at small details rather than complex parts of the road as a structure. Combinations of performance requirements that leave the contractor with no choice were mentioned, nevertheless. Requirements may thus in a given context point clearly to a single technical solution, which could instead have been identified by the client in a prescriptive specification: an example concerning requirements on road lighting systems was mentioned. It was also pointed out that clients should follow a clear policy of what is to be counted as prescriptive specification and what is of a performance nature; otherwise, relations between contractor and client may be damaged by the contractor being tempted to exploit what can be claimed to be contradictory specifications. Another challenge is when performance specifications include references to client documents that contain prescriptive language or happen to refer in their turn to older administrative and technical documents with prescriptive content.

The best choice between prescriptive and performance style was felt less than obvious for lighting, colours, trees and vegetation in general, both for initial construction and for operation and maintenance in the long run. Exhaustive specifications for vegetation, regardless of being prescriptive or in performance terms, were believed to be difficult to formulate or very lengthy. Furthermore, they also suffer from verification issues along the time axis. One contractor project manager emphasized the disadvantages of extensive documentation of performance specifications which tended to be much the same for projects with low contract sums and those that are large. None of the project managers claimed that there were problems with measuring the fulfilment of performance-based requirements or when interpreting measurement data.

Except for standard clauses defining penalties for schedule overruns, no quality of performance penalties or – with one exception - bonuses were reported. Two projects received a bonus or a special payment for early completion. For the project with a twenty-year warranty, there was a bonus for accidents being fewer than 18 for three years. Project managers did not see questions of extent of and responsibility for geotechnical information as relevant to performance issues.

Discussion and conclusions

It is along the time axis that three major obstacles to innovation arise, according to the findings here. Before the contractor is able to develop innovative solutions, the initial design plan curtailed fundamental geometrical features. Once the contractor has been appointed, the mix of performance and prescriptive requirement formulations is more of a challenge than clashes between performance requirements in themselves. One reason for the client avoiding performance language, clearly more so for bridges rather than road surfaces, appears to be concern with efficiency in future maintenance of the structure.

Considering the hierarchy of requirements, the successive phases are too separated from each other when overarching transportation values are broken down into more precise requirements; local environmental effects have been handled in the pre-construction phase, and the economic efficiency of maintenance and operations relates to the post-construction phase. A client's transition from detailed specifications to performance specifications for the construction phase can be either bottom-up or top-down. Bottom-up is a strategy where existing detailed specifications are analysed and then transformed into performance formulations. When possible, this includes merger of intentions between more than a single specification detail. A more ambitious strategy is top-down, starting with a minimal set of very broad functions (e.g. for a bridge: "support transport from A to B while allowing passage under the bridge"). The more detailed the performance-based requirements successively are, the less there will be scope for radical technological innovations. In the six projects analysed here, we note an absence of conflicts arising from collisions of performance requirements and from different interpretations of performance tests. One explanation could be that the scope for innovations was narrow, due to the actual specifications.

The position that has been argued here is that the concept of performance-based requirements should be reserved for requirements that concern measurable properties of a structure or parts of a structure; also, that the requirements should refer to a certain point of time and change of properties over time, where this is applicable. The question of when to measure is crucial; early measurement, perhaps already while construction is still ongoing, is associated with low hierarchical levels and weak incentives for radical technology innovation.

In technical descriptions, the term performance-based requirements ought to be limited to requirements where the fulfilment of the requirement is associated with a measuring method. Unaided ocular inspections should be seen as typically associated with execution (prescriptive) requirements. Therefore, aesthetic requirements can be taken as examples of requirements that ought to be regarded as execution requirements of a moderate detailing degree.

A more distinct model for specifying performance-based requirements in technical descriptions ought to be considered. In this model, distinctions should be made between performance-based requirements on different levels with reference to suitable measuring methods. Efforts for developing such a model need to consider current work on digitalization of processes.

This project has highlighted the difference in Swedish requirements between roads and bridges. For roads, there are frequent performance-based requirements concerning primarily service life, load-carrying capacity, evenness, and friction. For bridges, the performance-based requirements (if any) are currently on a low (or more detailed) level. Defining performance-based requirements on a higher level also for bridge construction and bridge maintenance should be considered in order to promote alternative and innovative technical solutions. There appears to be a potential for using performance specifications to a greater extent for both construction and maintenance of bridges. These specifications should be founded on analyses of probable life cycle costs. Preventative maintenance for a number of bridges could be procured based on bridge status assessments before and after the contractual period.

To make pavement materials and technologies with a longer service life but higher construction costs more competitive, the warranty period has to be long. In Poland, with a climate similar to Sweden, more than 410 km of concrete motorways have recently been constructed (Deja and Kijowski, 2010; Nazarko et al., 2015). One important reason for selecting concrete was that design-build-operate contracts running for several decades were procured.

General routines enabling early involvement and use of contractors' technical skills, already at the design plan stage, should be developed. An alternative is to introduce flexible routines for reconsidering the design plan when a contractor has been selected. The aim is to enable a total and flexible optimization of the use of natural and other resources, not least for obtaining an improved balance between different environmental requirements.

Further development is needed to promote technical innovations in the context of design-build projects. A shift towards less detailed specifications and a move towards design-build-operate contracts with prolonged maintenance responsibility would also encourage the choice of more sustainable solutions. The emphasis on life-cycle costing in the reformulated contract award criteria in the EU public procurement directive (2014/24/EU, Articles 67, 68) might be insufficient to make many contractors willing to re-orientate their choice of pavement materials, unless specifications are supported by life cycle analyses and the choice of contract type is reconsidered to prioritize design-build arrangements. Technical research is needed in order to support competence development and to permit better predictions of the long-term sustainability of innovative solutions for both roads and bridges, including both construction and maintenance. These research efforts will have to be deployed within a life cycle perspective recognizing sustainability concerns.

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Appendix: Survey questions

The survey questions were divided into five main groups.

APPLICATION AREAS FOR PERFORMANCE-BASED REQUIREMENTS

In which aspects have performance-based requirements or detailed prescriptive requirements, respectively, been used?

Which are the probable motives behind the selection of requirement type?

Does the selection of requirement type correspond to the contractor's potential for innovative solutions?

EFFECTS OF PERFORMANCE-BASED REQUIREMENTS

Have the performance-based requirements resulted in innovations, and in that case which?

Which economic, timesaving, quality and performance improvements have the innovations resulted in?

Have the performance-based requirements caused any economic or construction time savings?

Have the effects on cost and construction time caused lower execution quality?

CONTRACT CLAUSES REGARDING BONUS AND PENALTY

Which clauses on bonus and/or penalty are included in the contract?

Are the clauses reasonable?

Have the clauses been used?

Did the clauses have any effect?

If there were no such clauses, how could they otherwise have been formulated?

INTERPRETATION QUESTIONS CONCERNING REQUIREMENT FULFILMENT

Problems due to interrelationships between different performance-based requirements

Problems due to vague limits between performance-based and detailed requirements

Problems with use of or lack of measuring method

Problems with interpretation of measuring data concerning requirement fulfilment

Problems due to difficulties to identify the causes of deficient requirement fulfilment

The relationship between the contractor's self-monitoring and the client's control of requirement fulfilment

QUESTIONS CONCERNING INFORMATION PROVIDED BY THE CLIENT

Extent of and responsibility for geotechnical information