Impact of market fluctuation on relative advantageousness of project delivery systems

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Abstract

An appropriate project delivery system is a key means for the owner to create preconditions for successful realisation of a project. The decision to use a certain system is likely the result of considering numerous factors since project owners and projects have divergent objectives and constraints. Market situation is one constraint, which can be expected to impact the relative capacities of project delivery systems to meet critical project objectives. There is, however, little research on that impact and existing project delivery system selection tools seem to ignore it.

To correct that shortcoming, this study focusses on the impact of market cycles on the expected preference for and use of various project delivery systems. Literature and expert interviews were utilised to generate understanding, which was then tested against market practice, based on extensive data on new building construction projects extending over a period of a quarter century. Shares of different project delivery systems were examined in relation to market situation separately for different building types. The method involved calculation of partial correlations, which eliminate the impact of intervening variables that complicate the relationship between the shares and the market situation. Changes in the use of different project delivery systems over time were also examined.

The results indicate that market situation is not a determinant. Yet, for instance, Construction Management methods become more advantageous as the market outlook improves. The traditional Comprehensive Contract (Design-Bid-Build), again, assumes a larger role as market trends weaken although a heated market is likely to make some of its users adopt the Separate Contracts method. Moreover, the study indicates that there has been a minor move towards increased use of Design-Build during the long period of examination.

Keywords

project delivery systems, procurement systems, buildings, new construction, market cycles, Finland, trends

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1. Introduction

The project delivery system (PDS; or procurement system) determines the division of labour and contractual and operational relations between the major players of a project as well as the scope of related competition. Therefore, it is a high-level organisational means of creating preconditions for the successful realisation of a building project. The right system may help avoid problems and be key to attaining project-specific goals. These goals may include quick project completion, low price, practical allocation of risk between the parties, small amount of in-house work, flexibility for late changes, and allowing the owner to affect the details of the design solution, etc. In addition to the owner's objectives, the type and size of the building in question are among factors, which also have an impact on the selection of the PDS.

A lot of work has been done to determine the rationality of the use of alternative PDSs. For instance, tools combining the case-specific valuations of the decision-maker and predefined relative performance capacities of different PDSs have been developed to assist the owner in the selection of a PDS (as shown below). These tools regularly ignore the market situation, or assume that a change in demand and supply does not alter the relative capacities of PDSs to meet critical objectives. Thus, it has not been possible to systematically take into account a change in the operating environment and its possible impact on the relative effectiveness or capacity of PDSs in selection.

Despite that deficiency, it is probable that as the market situation varies as a result of general economic fluctuation (typically with a minor delay), the relative merits and demerits of PDSs also change. The eagerness of contractors to submit proposals and their profit expectations vary. Resource availability and over- and underemployment issues also confront the owner's project organisation and construction sector companies every now and then. Consequently, it is logical to expect that explainable changes take place in the relative capacity of various PDSs to respond to the owner's objectives.

That view is supported by Love et al. (2008), who concluded that the procurement selection systems developed are deficient in that they ignore, for instance, market-related factors. The importance of current market conditions was emphasised also in the preceding focus group workshops with senior procurement (policy) managers who also agreed that an embedded culture of uncertainty avoidance invariably meant that familiar (traditional) methods are used instead of considering alternative procurement forms despite their obvious advantages (Love et al., 2008). This suggests that the impact of the market situation on practical decisions is smaller than it should be.

Kumaraswamy and Dissanayaka (1998) also list numerous factors potentially relevant in the selection of a PDS that are generally disregarded. Market conditions are among those factors, especially resource shortages in a booming market. Love et al. (2012) emphasise the importance of selecting a PDS that will elicit a good response from contractors in the current market situation. That is essential to maximise the competitiveness of the tender process and to secure an appropriately experienced and resourced contractor for the project.

The aim of this paper is to explore whether market situation plays a role in the selection of a PDS for a project. First, after an in-depth review of current knowledge, theoretical aspects that speak for or against any PDS in a certain market situation are presented based on a literature review and interviews. Second, the paper analyses the market behaviour of construction project owners if the role actually shows up in the market data and does not have a merely marginal impact totally overshadowed by other factors in practice. The applied method includes an analysis of the shares of PDSs used in new building construction in Finland over a 25-year period. Conclusions are drawn based on the congruence between theoretical views and market observations.

2. Premises and current knowledge

2.1. Breakdown of PDSs in the study

There are numerous PDSs for establishing the division of labour and contractual and managerial relations between the parties. In this study, the breakdown of systems is the following (in accordance with the breakdown of the database/source presented later):

- *In-house construction* (IH), where the owner designs or commissions the design, supervises site works and possibly performs part of the technical construction work.
- *Design-Build* (DB), where a contractor under contract to the owner is responsible for the project's design and construction as an entity.
- *Comprehensive Contract* (CC), where the owner assumes responsibility for design, and the project is implemented on the basis of a single contract; no subsidiary contracts are used.
- *Separate-Contracts* (SC), where the owner assumes responsibility for design, and construction is implemented on the basis of a few parallel contracts.
- *Construction Management* (CM), where a separate organisation manages the overall project, and implementation is realised through numerous partial contracts with strong owner involvement.

The In-house construction group comprises genuine client-initiated in-house projects and (speculative) development projects of construction companies. As to the breakdown of the client's procurement process alternatives, despite numerous variations and applications, they are conventionally classified into traditional Design-Bid-Build (ie, CC, SC), Management-type (CM) and Design-Construct-type (DB) methods on the roughest level of examination (eg, Chang and Ive, 2011; Dorsey, 1997; Konchar and Sanvido, 1998; Love et al., 1998; Masterman, 1992; Peltonen and Kiiras, 1998).

Thus, the breakdown adheres to general practice with the exception that a difference is made between Design-Bid-Build projects based on the utilisation of a single construction contract (CC) and a few parallel contracts (SC); in the latter case one contractor (usually the one in charge of the structural works) is in charge of co-ordination of the works by other/subsidiary contractors (eg, earth works, plumbing and sewerage, HVAC, electrical system). Such differentiation is not common in literature, but not totally unknown (eg, CMAA, 2012; Dorsey, 1997; Franks, 1990; the first two refer informatively to it as Multiple Prime Contracts and Separate Contracts). On the other hand, the breakdown does not differentiate between Construction Management with a fee and at risk, or the variations of Design-Build (turnkey, price competition, etc.).

Considering the absence and/or specific arrangements of other existing PDSs, such as Project Alliance (not yet used for new buildings during the examined period), Design-Build-Maintain and Design-Build-Finance-Operate (possible projects implemented based on several contracts including a DB contract), the above list of PDSs is reasonable and comprehensive, as it adheres to general practice and covers all the options used in the target market during the studied period. A review of numerous contemporary guides from earlier decades also reveals that DBB is the conventional mode of procuring buildings in Finland, but DB established itself long before the examination period. CM, again, is a more recent application as can be seen from the early data, where CM projects are missing.

2.2. Knowledge about the use of different PDSs

Based on a literature survey, there is very little research on the impact of economic or market situation on the use of alternative PDSs in construction. The study by Dowd (1996) is one of a few on that topic, but the results are far from explicit in the absence of exact data. The research focussed on past general trends in the industry. Increasing use of other than the Traditional (Comprehensive) Contract during the long period examined was recognised. It was also hypothesised that Management Contracts (CM) correlate directly with construction output due to the small number of very large projects implemented by this system in good economic times, and that use of Design-Build is inversely proportional to the industry's activity levels. Oyegoke et al. (2009), again, concluded that market behaviour, especially changes in demand and supply capacity, dictate the trends in procurement. Yet, they did not focus on the use of different/classified PDSs in various market situations.

Eadie et al. (2013) also recognised the potential impact of changing market volumes on used project procurement modes. They studied the topic through a survey of public sector procurement experts, but the collected data appeared to be partly contradictory. Yet, a transfer from Traditional to Design-Build was considered likely along with the increase in market volume although it is not quite clear whether the trend is of a more permanent, long-term nature. Likewise, Shiyamini et al. (2005) recognised increased use of Design-Build in the industrial building sector during economic growth periods obviously due to the urgent need for faster realisation.

Koskela et al. (1997) also noticed that during a boom, especially, clients favour short construction times. Chang and Ive (2011) pointed out that fast-tracking helps increase the projects net present value. That is true especially during an upswing, partly due to the fact that fast construction is less prone to inflated prices. As to speed of delivery, both the CM and DB methods are indisputably superior to the CC and SC systems (Chan, 1995; Chang and Ive, 2011; Konchar and Sanvido, 1998; Love et al., 1998: Peltonen and Kiiras, 1998). The mutual superiority of CM and DB is not as clear. CM is generally considered to beat DB (Chan, 1995; Chang and Ive, 2011; Love et al., 1998; Peltonen and Kiiras, 1998), but Konchar and Sanvido (1998) demonstrated that the opposite is true. Yet, they focussed on CM-at-risk only, which is considered slower than CM-at-fee (Love et al., 1998; Peltonen and Kiiras, 1998).

If knowledge generated by research on actual markets is inadequate and contradictory, much help cannot be expected from the type of research aimed at assisting the owner in the selection of an appropriate PDS for a project (eg, Alhazmi and McCaffer, 2000; Chan, 1995; Love et al., 1998; Mahdi and Alreshaid, 2005; Oyetunji and Anderson, 2006; Skitmore and Marsden, 1988). More comprehensive literature reviews of PDS selection have not produced any new viewpoints either as to the market situation. In addition to the thorough review made in connection of this study, Hosseini et al. (2016), Naoum and Egbu (2015) and Naoum and Egbu (2016) have also conducted comprehensive and transparent reviews of PDS selection, but seem to provide no answer concerning the influence of market fluctuations (based on additional source document checks). Thus, our knowledge has not increased since the claim of Kumaraswamy and Dissanayaka (1998), Love et al. (2008) and Love et al. (2012) that the market situation should also be considered in PDS selection.

Yet, there seems to be an exception. The PDS selection method developed by Peltonen and Kiiras (1998) takes the market situation into account systematically, but the fact that the work has only been published in Finnish has prevented international discussion about the method. Based on the market actors' views, the authors consider Construction Management a system especially suited during market expansion: break-down of the works minimises risks and fosters companies' willingness to submit a tender while there are no extensive contingencies included in the price tenders for small, short-term pieces of work. Thus, the basic utility factors assigned to a system are increased for an upswing and decreased for a downswing. The view is supported by Skitmore et al. (2006), who noted that construction owners are known to break trades to further increase competition (under inadequate supply).

In the case of Design-Build the situation is not as clear. Cost competitiveness of Design-Build improves in a recession, while the opposite is true in a boom, when contractors may be unwilling to take part in laborious Design-Build competitions that require making design proposals (Peltonen and Kiiras, 1998). In such a situation, DB contractors prefer the easier options available and better-paying self-developed projects. Skitmore and Smyth (2007) reported that DB is considered the most price sensitive to demand factors, although they confirm that sensitivity pertains to all PDSs. Yet, the cost certainty for the owner may well speak for Design-Build also in an upswing, although risk contingencies are likely to make it economically disadvantageous to the client. Peltonen and Kiiras (1998) noted also that Design-Build may prove profitable if the contract can be concluded before a boom starts.

3. Research methods

3.1. Overall approach

To start with, the study surveys theoretical aspects that speak for or against any PDS in a certain market situation. The survey consists of the (above) literature review and practitioners' semi-structured interviews on the rationality of their decision-making in PDS (or project) selection under varying market situations and related market observations. All the practitioners have long-term hands-on experience from industry practices and are senior level decision-makers on the applied procedures and arrangements. The group includes both public and private owners and contractors. The interviewees are the same that were involved in the preceding study stage (Lahdenperä, 2015), although different parts and aspects of the interviews are dealt with in separate papers.

Summation of the survey results produces 13 statements on the rational usage of various procurement solutions in various market situations. It is followed by an appraisal of the statements and subsequent formulation of a few hypotheses on the appropriateness of various PDSs in different situations. Finally, the study analyses the market behaviour of construction owners if related indicators included in the hypotheses seem to impact decisionmaking also in practice in a way that supports the presented logic of the statements on PDS selection.

3.2. Source information

As to actual market behaviour, the study is based on hard data on the use of PDSs in new building construction in Finland (RPT Docu, 2013). The project data are generated by continuous inquires to project owners on their projects and they cover various types of information on projects including eg, building type, project size and, in many cases, also the PDS used. The database recognises five alternative PDSs – *In-house construction, Design-Build*, *Comprehensive Contract*, *Separate-Contracts and Construction Management* introduced in the previous section of the paper.

The database and the principles of capturing data for this study are presented in Lahdenperä (2015). That paper was compiled to make this study transparent as to data. First, it presents and visualises data on market activity and the use and shares of various PDSs per building type in accordance with the division/classification used in this study; the shares were determined on the basis of the number of projects implemented by each PDS. Second, it determines whether the data are usable for the analysis of this study. It also aims to reveal possible market factors that explain the seemingly irrational changes in the use of different PDSs that weaken the statistical significance of the results. The reformed data set includes a total of 41,259 projects quite evenly distributed over the 25-year target period consistent with market trends, and it covers a significant share of the targeted business.

Yet, In-house construction is excluded from the examination since it is seldom a real alternative to other PDSs. This is most obvious in housing construction, where In-house projects are used only in speculative development by construction companies. They just establish a housing company, in whose name they act, and whose shares entitling to occupy dwellings they subsequently sell to consumers (or investors more recently). Although this activity is clearly linked to demand and market conditions, it does not involve actual selection between alternative PDSs in a client-initiated project. In other building types, the group comprises both user-/owner-initiated in-house projects and speculative development projects, but since their screening was not possible, the same practice is followed in case of all building types to be on the safe side. Due to the exclusion, the data consists now of 25,748 projects.

The calculations are made for new building construction as a whole (ie, All), and the key groups of building types in accordance with the official classification (Statistic Finland, 1994), ie, residential, industrial and business premises, as well as other buildings – mainly public service buildings. The unitary calculations (All) are based on the whole set of data as such without any attempt to weight the figures by building type-specific market shares due to lack of ratios for weighting: construction volume statistics are in cubic metres while project sizes are only expressed by monetary value, and the ratios between building types vary a lot.

Actualised construction activity represents the contemporary understanding of market conditions (fluctuation). It is depicted by the volumes of new building starts each year as presented by the official statistics (Statistic Finland, 2014a) and illustrates the situations in which a PDS is selected. Thus, ex post data on market activity was used instead of ex ante outlooks on market development although it is the latter on which decisionmakers lean, when selecting a PDS for a project. Construction owners seem to be well informed about the situation due to plenty of foresight information provided by a governmental task force, private service providers and the national federation for construction owners among others. Although literal follow-ups are missing, according to anecdotal evidence, foresights do well in anticipating forthcoming development and turns in the near future. Therefore, the deviation can be considered negligible. On the other hand, also the need for transparency, unambiguity and comprehensiveness speak for official statistics, which can mitigate possible timing and discontinuity issues related to various foresights.

Total new building construction start volumes were also used in the case of building type-specific calculations, since production capacity adjusts flexibly from one building type to another, as also observed by Hillebrandt (2000), Ball et al. (2000) and Skitmore et al. (2006), and total volume shapes the market boundary conditions to a larger extent than building type-specific construction volumes.

3.3. Used methods of calculation

In the calculations, the impact of market situation on the use of various PDSs was evaluated by correlation analysis. The calculations started by determining *the Pearson product-moment correlation coefficient* between all pairs of *PDS share*, *construction activity*, *time* and *average project size* per building type and all buildings. Time and project size needed to be included to eliminate the impact of these intervening/contributing factors of the bilateral scores of a PDS's share and construction activity by further calculations. This was due to the fact that project size is also of major importance in the selection of the PDS (cf. Dowd, 1996; Lahdenperä, 2001; Lahdenperä, 2015). The initial study Lahdenperä (2015) also indicates (based on the same data used in this study) that average project size has increased over time despite the elimination of the impact of the time value of money (provided by Statistic Finland, 2014b). This way, project size is also connected to the progress of time, which also needs to be considered separately since there is clear indication that some PDSs may become more popular in the course of time (Davis Langdon, 2012; Dowd, 1996; Duggan and Patel, 2014; Eadie et al., 2013).

The elimination of intervening factors was accomplished by using direct correlation coefficients and calculating the so-called first order partial correlations (elimination of the impact of one variable on the relationship between the other two), which were then used to calculate second order partial correlations (eventually eliminating the impact of two intervening variables). The process and formulas (eg, Wetcher-Hendricks, 2014; Yule, 1922) are explained comprehensively in Appendix 1.

The resulting correlation scores depict, first, the direct relation between a PDS's share and market fluctuation (where the impact of both project size and general development over time were eliminated) to serve the testing of hypotheses (in accordance with the research question). The scores are presented both by using absolute PDS shares and absolute construction volumes (Table 5 below) or their annual changes (Table 6 below) as input data; in the latter case project size was also taken into account as an annual change – otherwise absolute values were used. (The average size of a building type is used throughout the calculations instead of the sizes of projects implemented by the PDSs under examination in each case.) Variables derived for both cases are summarised in Table 1 (the two leftmost cases). Tables 2 and 3 present simple descriptive statistics for these derivative variables based on the initial data.

As to the complementary calculations performed, both were considered necessary. The use of absolute values (Table 5) may be generally acceptable, but due to the long examination period and radical changes in the construction volumes, they ignore the resulting adjustments in the industry's capacity. Calculations based on annual changes (Table 6) take adjustments better into account, but are not without flaws either. Thus, the former responds literally to questions related to market activity (boom, recession) whereas

Table 1 Description of basic variables of the study and their use in the parallel calculations (further clarified at the bottom of the table)

Variable	Basic description	Additional remarks on variables per examination		
		Absolute annual volume	Annual change in volume	Passing of time
PDS's share	A number of projects by a certain PDS in relation to number of projects in a reference group (typically all projects of the data) during a year; per building type or all buildings as appropriate [%]	*absolute* ratio as such	*changes* in ratios between consecutive years	*absolute* ratio as such
Construction activity	Construction starts of all included building types during a calendar year [market volume in cubic metres]	*absolute* values as such	*changes* in values between consecutive years	*absolute* values as such
Project size	Average size of all projects per building type or all buildings, as appropriate, despite the PDS used [in 2013 Euros by eliminating the temporal changes in value of money]	*absolute* values as such	*changes* in values between consecutive years	*absolute* values as such
Time	Ordinal number of a year	*absolute* values	*absolute* values	*absolute* values
	Correlations (second order)	PDS's share, Construction activity	PDS's share, Construction activity	PDS's share, Time
	Eliminated factors	Project size, Time	Project size, Time	Construction activity, Project size
	Descriptive statistics	Table 2	Table 3	Table 2
	Pesentation of results	Table 5	Table 6	Table 7

the latter satisfies the curiosity related to market changes (upswing, downswing).

Second, correlation scores between PDS shares and time (where the impact of both construction activity and project size were eliminated when all variables were represented by absolute values; the rightmost case in Table 1) were also calculated to determine whether any trend in the use of various PDSs could be observed that was independent of market fluctuation or varying project sizes during the study period (Table 7 below). This was a complementary effort considered appropriate due to the above presented observations on general trends and the inclusion of progress of time into the analysis.

Table 2 Descriptive statistics of absolute annual figures over the total examination period

		Average					**Standard deviation**				
Variable	**[units]**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**
Share of PDS											
Construction Management (CM)	[%]	1.6	2.7	6.6	2.2	2.6	2.2	2.1	4.8	1.6	2.0
Comprehensive Contract (CC)	[%]	35.5	15.8	10.8	13.3	23.2	15.6	6.1	3.6	3.5	10.3
Separate-Contracts (SC)	[%]	37.6	64.2	62.9	73.5	55.7	9.2	10.3	7.2	4.9	6.0
Design-Build (DB)	[%]	25.3	17.3	19.7	11.1	18.5	10.7	6.1	5.3	4.7	5.1
Other variables											
Construction activity	[Mill. m^3]	23.133	23.133	23.133	23.133	23.133	6.195	6.195	6.195	6.195	6.195
Project size	[MEUR]	2.871	3.868	6.842	3.943	3.921	0.773	1.280	2.363	1.154	1.151

Table 3 Descriptive statistics of changes in annual figures over the total examination period

		Average					Standard deviation				
Variable	**[units]**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**
Share of PDS											
Construction Management (CM)	[Δ%]	0.05	0.17	0.38	0.08	0.10	2.15	2.10	4.98	1.35	1.07
Comprehensive Contract (CC)	[Δ%]	–1.05	0.55	0.23	0.17	–0.36	5.50	4.77	3.36	2.50	3.62
Separate-Contracts (SC)	[Δ%]	1.02	–1.02	–0.43	–0.31	0.26	8.86	6.00	7.44	3.80	4.09
Design-Build (DB)	[Δ%]	–0.02	0.30	–0.18	0.07	0.00	8.52	6.36	6.24	3.36	3.41
Other variables											
Construction activity	[ΔMill. m^3]	–0.889	–0.889	–0.889	–0.889	–0.889	4.551	4.551	4.551	4.551	4.551
Project size	[ΔMEUR]	0.090	0.070	0.346	0.137	0.127	0.377	1.788	1.843	0.951	0.524

Depending on how closely the statistical relationship between two variables resembles linear correlation, the value of the derived correlation scores ranges from –1 (full inverse correlation) to +1 (full positive correlation). When the correlation coefficient of two variables is raised to the second power, the result is the so-called *coefficient of determination*, and the independent variable determines the variation in the dependent variable to the extent of the coefficient of determination (often logically presented as a percentage). The rest is due to other contributing factors and random variation.

Finally, the standard *t*-test procedure was followed to test the statistical significance of the correlation coefficients. First, the null hypothesis (H0) was specified separately for each of the eventual 240 (second order partial) correlation coefficients of the study (eg, $H0_1$ for H1 in a certain situation) which suggests that correlation does not exist (which, eg, H1 suggests to exist). *P* values were then determined by a two-tailed test referring to a *t*-distribution where small *p* values (eg, <0.01) gave a reason to reject the null hypothesis in favour of the alternative hypothesis (eg, H1), meaning that we may expect that the correlation is statistically significant (eg, *p* value <0.01 indicates an impact probability of >99%). *P* values are presented (in Table 8 below) for all examinations covering the 'combined 1989–2013 period' and, besides, the significance level is indicated by asterisks (*) for all examinations in connection with correlation coefficients where applicable (ie, Tables 5–7).

4. Theoretical applicability of PDSs to various market situations

4.1. Views on market cycles and their impact on PDS selection

The survey on the impact of the market situation on PDS selection is summarised as discrete statements in Table 4 to avoid idle speculation. Most of the views come from expert interviews due to the relatively small number of views on the topic in literature. Yet, the above presented literature survey had an impact (esp. Peltonen and Kiiras, 1998). Besides, some ideas come from an earlier survey (Lahdenperä, 2000). In any case, a statement was included in the table, if the source/interviewee presented it unprompted accompanied with sound argumentation. In the table, the 'Source' column (S) refers to the source of the statement presented in each row: whether literature (L) or interviews (I).

In addition to actual statements, the table concretises their supposed impact on the usability of alternative PDSs, ie, improved (+) or deteriorated (–) competitiveness. To facilitate comparison and drawing of joint conclusions from all statements, the impact is presented in relation to market upswing and/or boom in all cases despite the fact that the wording of some statements (nos. 1, 5, 7, 10, 12) presents the idea in relation to downturn or recession in accordance with the source. Therefore, the impact assessment symbols depict a reverse or opposite situation in these cases. The table also shows whether the considered impact exists mainly due to a certain change (C) or level (L) of construction activity.

In PDS selection the market situation/outlook is manifested mainly in the price formation of a project. Some cite cost certainty, but in most cases, cost efficiency and how it can be best attained matter most. Thus, the correlation between market activity and prices was already built into the statements. On the other hand, Akintoye et al. (1998), Lahdenperä (2000) and Skitmore et al. (2006) have demonstrated that changes in construction volumes are one of the leading indicators of construction contract prices, which confirms the rationality of the statements in this regard. In addition to pricing, availability of tenders, resourcing, changes in the owner's constraints, even plot supply, may impact PDS selection.

4.2. Formulation of hypotheses

Based on the statements in Table 4, some assumptions can be made. First, the CM system is, above all, a PDS for times of market expansion; whether an upswing (C) or a booming market (L). There is little doubt about that since all views (2–4, 11–13) except one weak signal (8) tell the same thing despite the varying position of the other PDSs per statement. It can also be expected that skillful resources are available to fill the role of the

Table 4 Impact statements and resulting changes in primacy of PDSs in a market upswing or boom

	Source			**Market situation**		**Project delivery system (PDS)**			
#	**L**	**I**		**C**	**L**	**DB**	**CC**	**SC**	**CM**
			Changes in relative performance/capacity						
1	✓		The use of SC or CC offers the possibility to involve the contractor(s) at the latest possible stage (due to a separate design commission preceding the call for tenders) whereby it may allow the owner to obtain a lower offer(s) from the market in a downturn, ie, especially in relation to DB.	✓		+	–	–	
2	✓		During a market upswing the interest of contractors towards laborious DB competitions (other than negotiated contracts) requiring design proposals decreases along with the inflated contingencies due to an expected rise in subcontracting prices, which makes DB less competitive in an upswing and boom.	✓	✓	–	+	+	+
3	✓		In CM the project is broken down into numerous small works/contracts which increases the number of potential contractors and, moreover, competition while there are no extensive contingencies in small short-term pieces of work; therefore CM is a method for market expansion and booming seasons.	✓	✓	–	–	–	+
4		✓	In an upswing tenders for a fixed-price contract include extensive contingencies due to expected rise in subcontractor prices, and, thus, the owner benefits from the use of cost reimbursement methods based on an open-books practice (cost-plus type contracts) that are actively used in CM projects but less in others.	✓	✓		–	–	+
5		✓	Construction companies purchase plots for their own development projects (IH), especially ones undertaken in a good market situation, but a recession may drive them to sacrifice a plot to close a deal in order to maintain a reasonable workload; the practice may result in the use of DB contracts instead of CC or SC.	✓	✓	–	+	+	
6	✓		In comparison to CC, SC allows using different forms of main and subsidiary contracts, as appropriate, creating more competition and being, thus, advantageous to the owner during a boom; it also allows non-simultaneous procurements which may well serve the same purpose.		✓		–	+	
7	✓	✓	In a boom, CC results in a higher price to the owner than SC due to the extra fees and risk assumed and priced into the tender, whereas in a recession CCs are offered at such cheap prices that SC is not worth considering, since builders want to employ as much of their own resources as possible by omitting extras.		✓		–	+	

Continued

Table 4 Continued

	Source			Market situation		Project delivery system (PDS)			
#	L	I		C	L	DB	CC	SC	CM
8		✓	In a boom, when other options exist in the market, all contractors are not willing to work as a CM contractor since the paid fee is relatively low due to the risk assumed by the owner; thus, the unavailability of the best-in-class resources for major projects may hinder the use of CM in some cases.		✓	+			–
			Changes in the owner's objectives						
9	✓		A boom and the consequent brisk construction activity may cause a shortage of experienced staff to the owner; then a risk-transfer contract including design liability, ie, DB, may solve the problem by allowing transfer of all responsibility for project management and related risks to the contractor.		✓	+	–	–	
10		✓	Tight economic situations call for financial discipline in owner organisations and use of the price criterion in the selection of contractors, which may result in transition from DB with (at least) some leeway and diverse selection criteria to other PDSs with price-based selection aimed at providing low prices.		✓	+	–	–	
11		✓	During a boom accompanied by improvement in the financial situation, the owner often gets rid of the exclusive use of the price criterion in contractor selection, which offers a possibility to apply more development-oriented, collaborative project practices that are available within the DB and CM frameworks.		✓	+	–	–	+
12		✓	Tight economic situations require financial discipline and the use of fixed-price contracts, since the owner needs a reliable price for an entire project for an investment decision and is unwilling to commit to the project without such certainty; CC and SC, and DB in many cases, offer this option.		✓	–	–	–	+
13	✓		Fast delivery may be required by the owner's future business prospects, especially when the economic outlook is positive, ie, to improve the net present value of the investment by accelerating the stream of revenue and by minimising investment cost escalation; CM and DB enable shorter delivery times than CC and SC.	✓	✓	+	–	–	+

construction manager despite the market situation, since it is a solid operational model for a number of service providers.

Further, there seems to be consensus on the position of the CC and SC methods. Compared to the other two PDSs, their position is identical in all comparisons (1–5, 9–13), based on the fact that in both systems (that are variations of the Design-Bid-Build method) design is largely made before the involvement of the contractor, and, therefore, in relation to DB and CM, they work analogously. All the statements do not have a practical effect at the market level (ie, 5) and, therefore, as far as tenders exist for DB projects (2), the Design-Bid-Build variations tend to be more suitable at times of poor market outlook based on the numerous related assertions.

On the other hand, statements that focus only on the mutual difference of these two PDSs (6, 7) also make it clear that SC is relatively more suitable for periods of high production volumes (and CC for low volumes) because of the level of competition and the pricing of risk. Therefore, based on this view and those of the previous paragraph, it can be assumed that CC invariably is suitable for low volume periods although the evaluation of the appropriateness of SC is much more challenging.

The position of DB is not clear either, since individual statements lead to different inferences, and it would be too speculative to weight the views differently. Yet, comparison to Design-Bid-Build systems suggests that preference for DB may well increase as the market outlook improves (1, 9, 10, 11, 13 for; 2, 5 against). However, it is likely that DB lags behind CM as a PDS for good economic conditions due to the relatively few signs supporting preference for it under such conditions (8 for; 2, 3, 12 against).

If the above reasoning is logical, the following hypotheses can be presented for further examination:

- H1 The share of DB in relation to the combined share of CC and SC increases the more, the better the market outlook.
- H2 The share of SC in relation to the share of CC increases the more, the better the market outlook.
- H3 The share of CM increases the more, the better the market outlook.
- H4 The share of CC diminishes the more, the better the market outlook.

Besides, the relative preferences for DB and SC are also worth examining although they cannot be positively inferred from the above statements unlike those for CC and CM. Some signals about preference for them exists, however, and if loose working hypotheses are allowed for the purposes of arousing discussion and referencing, the following are proposed:

- H5 The share of SC diminishes the more, the better the market outlook.
- H6 The share of DB increases the more, the better the market outlook.

5. Application of PDSs in various market situations

5.1. Results of calculations related to market situations

The calculations indicate that the share of DB in relation to the combined share of CC and SC generally increases the more, the better the market outlook (in accordance with H1). If housing construction is excluded, most building type-specific correlations of the total (combined) examination period are statistically significant while the exceptions get a coefficient of 0.29 based on both absolute figures and changes (Tables 5 and 6). Periodical examinations, however, make the findings questionable. Especially the negative coefficients of industrial and business premises construction during the first examination period are puzzling although they may be the result of the chaos and restructuring of the industry due to radical drops in construction activity in the early 1990's that called normal market rationality into question.

In the case of housing, correlations are positive for the first examination period while those for the second are negative. The latter may be partly explained by the observed situation-specific structural changes in the market (see Lahdenperä, 2015: state-subsidised production and financial stimulus due to the crisis in 2009) resulting in the use of DB instead of CC and SC.

Moreover, as volumes increase, the share of SC in relation to the share of CC seems to increase in all building types. Although there is naturally variation, and all the correlations are not statistically significant, most figures are rather close whether considering the combined examination period or its parts. Neither does it make a substantial difference whether annual volumes or changes in construction activity are used (eg, 0.47* vs. 0.53**; see Table 8 below for exact *p* values). This supports the reasonableness of the corresponding hypothesis (H2).

Table 5 Second order partial correlation coefficients of absolute PDS share and construction volume

	First period 1989 – 2000					Second period 2001 – 2013					Combined period 1989 – 2013				
Hypothesis	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**
H1 $DB_{sc,cc}$[a]	0.14	0.81**	–0.09	0.84***	0.80**	–0.29	0.49	0.64*	0.34	0.02	0.03	0.62***	0.29	0.54**	0.42*
H2 SC_{cc}[b]	0.69*	0.42	0.52	0.72**	0.93***	0.14	0.47	0.57*	0.68*	0.50	0.29	0.33	0.41*	0.47*	0.47*
H3 CM_{all}[c]	–0.04	0.14	0.27	0.42	0.70*	0.57*	0.08	0.45	0.66*	0.79**	0.25	0.09	0.05	0.29	0.30
H4 CC_{all}[c]	–0.57	–0.59*	–0.54	–0.81**	–0.96***	0.01	–0.48	–0.74**	–0.73**	–0.58*	–0.25	–0.42*	–0.47*	–0.59**	–0.54**
H5 SC_{all}[c]	0.53	–0.30	0.35	–0.27	0.79**	0.16	0.07	–0.51	–0.04	0.15	0.28	–0.13	0.02	–0.13	0.36
H6 DB_{all}[c]	0.14	0.80**	–0.14	0.84***	0.80**	–0.32	0.48	0.59*	0.28	–0.06	0.02	0.61**	0.26	0.53**	0.41*

Asterisks depict statistical significance: * significant (prob. 95%), ** very significant (99%) and *** extremely significant (99.9%); figures w/o asterisks are statistically insignificant.
[a]The share of the PDS (ie, DB) is calculated in relation to total number of DB, SC and CC projects.
[b]The share of the PDS (ie, SC) is calculated in relation to total number of SC and CC projects.
[c]The share of the PDS in question is calculated in relation to total number of all projects (incl. CM, SC, CC and DB).

Table 6 Second order partial correlation coefficients of changes in PDS share and construction volume

	First period 1989 – 2000					Second period 2000 – 2013					Combined period 1989 – 2013				
Hypothesis	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**
H1 $DB_{sc,cc}$ [a]	0.50	–0.38	–0.45	0.06	0.30	–0.67*	0.38	0.80**	0.59*	0.18	–0.23	0.29	0.47*	0.52**	0.35
H2 SC_{cc} [b]	0.43	0.78**	0.35	0.40	0.70*	0.09	0.62*	0.13	0.17	–0.03	0.25	0.54**	0.29	0.31	0.53**
H3 CM_{all} [c]	–0.04	0.24	0.25	0.31	0.30	0.37	–0.33	0.17	0.18	0.47	0.24	–0.07	0.20	0.24	0.46*
H4 CC_{all} [c]	–0.78**	–0.76**	–0.33	–0.44	–0.79**	0.31	–0.60*	–0.49	–0.32	0.01	–0.23	–0.55**	–0.41*	–0.42*	–0.68***
H5 C_{all} [c]	0.08	0.78**	0.37	0.22	0.38	0.36	0.15	–0.69**	–0.47	–0.25	0.31	0.17	–0.27	–0.27	0.21
H6 DB_{all} [c]	0.51	–0.37	–0.45	0.06	0.24	–0.68*	0.40	0.78**	0.59*	0.12	–0.23	0.29	0.42*	0.51*	0.33

Asterisks depict statistical significance: * significant (prob. 95%), ** very significant (99%) and *** extremely significant (99.9%); figures w/o asterisks are statistically insignificant.
[a] The share of the PDS (ie, DB) is calculated in relation to total number of DB, SC and CC projects.
[b] The share of the PDS (ie, SC) is calculated in relation to total number of SC and CC projects.
[c] The share of the PDS in question is calculated in relation to total number of all projects (incl. CM, SC, CC and DB).

In the case of the share of CM, statistically significant correlation scores can be found among the periodic examinations based on absolute construction volumes (H3). In the case of changes in volumes, only the score for the whole group of projects (ie, All) over the combined study period is statistically significant (0.46*). The share of CM is, however, generally so small that the calculations are likely to be very sensitive to even minor changes for whatever reasons.

The correlations between the share of CC and promising market conditions are mainly inverse and, as such, relatively strong (eg, unitary figures for the combined examination period are –0.54** and –0.68***). In the case of periodic examinations, an exception exists as regards housing in the second period (change in values), however. The reason for it may, once again, be the temporary change in regulations and the 2009 financial stimulus due to the crisis referred to above (in the review of H1). Considering the exceptionality, there is no reason to reject the related hypothesis (H4).

In the case of SC and DB, the above theoretical discussion produced no definitive understanding of their popularity in various market cycles (H5, H6). The calculations for SC made no difference either. Although it seems that statistically significant scores were found in the periodical examinations, the figures for different building types and periods are contradictory, and mostly insignificant. Therefore, the examination does not support the related working hypothesis (H5) or even its opposite.

The situation is quite the same with DB, if the scores based on annual changes are considered. The scores are contradictory, even if housing construction is excluded on the basis of the above discussed irrationality, which likely contributes to the bias there. Thus, in this regard, the results question the validity of the hypothesis (H6). Yet, the results based on absolute values are much more supportive. Strong scores were calculated for industrial and other buildings in the first examination period while the ones for the combined period are also statistically significant (0.61**, 0.53**). A high absolute construction volume tends to lead to more active use of DB (as suggested by H6).

5.2. Results of calculations on long-terms trends

As regards long-term trends in the use of different PDSs (Table 7), there seems to be a clear winner. The combined examination period showed the biggest correlation for DB (0.56**; Table 8 for exact *p* values), meaning that it has been gaining popularity although all the periodical scores do not support the idea. On the other hand, it would be an overstatement to say the same about CM or SC. The CM method, indeed, appeared in the data for the first time in the middle of the first examination period, which explains the extremely high correlation figures then, but the increase did not actualise during the second period except in housing, where the method is used only occasionally (for PDSs' shares, see Lahdenperä, 2015). In the case of DB, the increase has been stronger after the first examination period, but, once again, housing construction seems to be an exception.

At first sight, the loser in the transition seems to be the CC system. The overall figure (–0.49*) does not describe the situation with all building types, however. The trends during the first and second examination periods were also very different. In the former a decrease occurred in the use of CC while the opposite was true with the latter; all building types moved in parallel within each period without exception. Interpretation of the development of the use of the SC system is as challenging. Most of the building types showed negative correlation in both examination periods and SC seemed to lose relative market share in their case. Yet, housing construction developed in the opposite direction, which does not allow drawing general conclusions without further examination.

6. Discussion

The study is based on an analysis of extensive data that cover a period of 25 years and include more than one thousand projects per year, on average, as well as reliable statistics on market volumes. That offers a solid foundation for the study. Yet, it is far from exhaustive.

To begin with, the rough research method based on annual summary figures led to a small

Table 7 Second order partial correlation coefficients of PDS share and passing of time

	First period 1989 – 2000					Second period 2001 – 2013					Combined period 1989 – 2013				
PDS	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**	**Housing**	**Industrial**	**Business Premises**	**Other**	**All**
CM	0.38	0.80**	0.78**	0.82**	0.89***	0.62*	–0.19	–0.33	–0.06	0.45	0.59**	0.66***	0.18	0.38	0.16
CC	–0.84***	–0.16	–0.37	–0.70*	–0.97***	0.20	0.71**	0.71**	0.69**	0.29	–0.57**	0.54**	0.02	–0.24	–0.49*
SC	0.59*	–0.42	–0.01	–0.10	0.69*	0.22	–0.89***	–0.67*	–0.92***	–0.39	0.57**	–0.80***	–0.33	–0.46*	0.19
DB	0.59*	0.49	–0.49	0.52	0.88***	–0.45	0.67*	0.67*	0.89***	0.19	0.09	0.63***	0.26	0.60**	0.56**

Asterisks depict statistical significance: * significant (prob. 95%), ** very significant (99%) and *** extremely significant (99.9%); figures w/o asterisks are statistically insignificant.

Table 8 *P* values of null hypothesis testing for the second order partial correlation coefficients of the combined 1989–2013 period figures

		Absolute annual volume (cf. Table 5)					**Annual change in volume (cf. Table 6)**					**Passing of time (cf. Table 7)**				
Hypothesis	PDS	Housing	Industrial	Bus. Premises	Other	All	Housing	Industrial	Bus. Premises	Other	All	Housing	Industrial	Bus. Premises	Other	All
$H0_1$	$DB_{sc,cc}$ [a]	0.890	<0.001	0.153	0.005	0.035	0.288	0.174	0.020	0.009	0.095					
$H0_2$	SC_{cc} [b]	0.164	0.109	0.039	0.019	0.017	0.234	0.007	0.168	0.141	0.008					
$H0_3$	CM_{all} [c]	0.230	0.684	0.825	0.160	0.149	0.261	0.737	0.345	0.258	0.023	0.002	<0.001	0.398	0.063	0.436
$H0_4$	CC_{all} [c]	0.222	0.039	0.018	0.002	0.005	0.284	0.006	0.047	0.043	<0.001	0.003	0.006	0.939	0.254	0.012
$H0_5$	SC_{all} [c]	0.182	0.524	0.918	0.550	0.073	0.144	0.435	0.210	0.210	0.330	0.003	<0.001	0.107	0.020	0.368
$H0_6$	DB_{all} [c]	0.922	0.001	0.205	0.006	0.042	0.281	0.170	0.040	0.011	0.117	0.660	<0.001	0.213	0.001	0.003

[a]The share of the PDS (ie, DB) is calculated in relation to total number of DB, SC and CC projects.
[b]The share of the PDS (ie, SC) is calculated in relation to total number of SC and CC projects.
[c]The share of the PDS in question is calculated in relation to total number of all projects (CM, SC, CC and DB).

sample from the viewpoint of statistical analysis. As a result, Probability Values (*p* values) tended to remain at a level that did not ensure the significance of the results. Besides, the wide variation between comparative scores casts a shadow of doubt also over statistically significant scores.

It is also clear that market changes do not take place just between calendar years, but may also occur in the course of a year. This suggests that the use of shorter intervals would have improved the precision and significance of the results. Yet, time increments shorter than a year were undesirable, since, for climatic reasons, there is considerable seasonal variation (within a year) in construction starts in Finland. Monthly numbers, for instance, would have led to a distorted picture of the phenomenon. Moreover, there is no indication that such seasonal fluctuation has an effect on prices and the rationality of the selection under study. These facts support the selected approach for this exploratory opening even though it is imperfect and even likely to ignore significant impacts.

As regards the rough research method, another challenge is the general classification of PDSs in the data. Variations of the PDSs also exist, especially of DB and CM, in terms of competition arrangements and selection criteria, risk transfer and resulting fee expectations, payment methods, etc. The rationality of the use of PDS variations also varies, and the rough data are unable to shed light on related factors: one factor may speak for one and another factor for another variation of the same PDS. This may well result in a situation where the summed up data indicate no rational behaviour. Applicability based on certain simplified grounds gets blurred.

Other events may also skew the shares of PDSs from the viewpoint of normal rational decision-making. For instance, when speculative housing construction activity fell as a result of the global financial crisis, the conditions for state subvention were relaxed temporarily as a stimulus to direct speculative projects already under preparation by construction companies towards production of rental housing (Lahdenperä, 2015). This increased the use of DB by rental housing investors temporarily – its impact has been recognised and was discussed above. Yet, it is also likely that other contributing events took place and factors emerged during the target period, but the study just did not detect them and their effect on the data.

On the other hand, the long target period included also market situations of various types that recurred, which improves the comprehensiveness of the period. However, the early years of the study period included an exceptionally hard recession leading to radical adjustments in the capacity of the industry, which poses the question of whether the situation is comparable to more recent fluctuations. Due to the adjustments in the industry, the simplified hypotheses of the study on market behaviour may not be manifested in the data as expected. That was a partial reason for conducting periodical examinations besides the aspiration to focus more on the more recent trends in the industry.

All of the above (use of summed up annual data; general classification of PDSs; unknown external impact factors; varying intensity of volume changes) means that the study is not likely to cover all aspects of existing rationality in the use of various PDSs from the viewpoint of market constraints. It is also likely that decision-makers behave irrationally from the viewpoint of the market situation by using PDSs they are used to applying (cf. above reference to Love et al., 2008, for instance). That suggests that the correlation scores based on the rough method of the study are likely to under-emphasise the phenomenon. It was also the reason why some scores were considered indicative although they were not statistically significant in all comparable cases.

Yet, some of the listed factors related to the market situation impact on the selection of a PDS (Table 4; lower section), but they all should not be considered to affect the relative capacities of PDSs, although their impact could not be eliminated from the data. Thus, they may have caused a reverse bias in relation to the factors discussed above that were found to dilute the statistical significance of the result. Besides, the impact of the exclusion of In-house construction from the examination and the lack of information on the possible use of index-linked contracts remains unclear.

Despite all mentioned inadequacies, this study deepens our understanding provided by earlier research on the topic. In general, it is congruent with Dowd (1996) in that the use of CM correlates directly with construction output, but the rationality of its use has now been explained. In the case of DB, the results are not unambiguous, which is not surprising since the results by Dowd (1996), Eadie et al. (2013) and Shiyamini et al. (2005) are also uncertain and contradictory. Yet, the study succeeds in shedding light on the mutual position of CC and SC. The study also collected a number of market-related decision-making guidelines for consideration in the development of PDS selection systems. This paves the way to more comprehensive understanding of the market conditions affecting PDS selection, which Kumaraswamy and Dissanayaka (1998) and Love et al. (2008) hope will become reality. As regards long-term trends (beyond market fluctuation), DB has been gaining popularity more recently and the situation resembles the development observed in other countries to some extent (eg, Davis Langdon, 2012; Duggan and Patel, 2014).

7. Conclusions

The study focussed on various PDSs and the relative preference for them in different market situations. There are numerous factors, which may affect the relative capacities of PDSs as the economy fluctuates. For instance, during a busy market

- contractors interest for laborious competitions that include making design proposals decreases as other possibilities exist
- contractors are less interested in spending their resources on low-fee management services when other more profitable business possibilities exist
- breaking of a project down into numerous contracts increases the number of potential contractors and competition and decreases layered fees and contingencies
- the fees and risk contingencies of a certain (comprehensive) contract are relatively higher than during stagnation and/or low market activity
- the tenders for a fixed-price contract include extensive fees and contingencies whereby the owner can benefit from the use of cost reimbursement contracts, and
- delayed entry into a contract and use of a construct-only method may allow the owner to benefit from the calming market later on.

Considering the conventional ternary approach of existing PDS selection systems (involving mainly DB, CC and CM), the above conclusions suggest that

- the relative advantageousness of CM improves in a boom, and
- the relative advantageousness of CC improves in a recession.

These two statements are also supported by the data, but not unreservedly, since the study is unable to eliminate the impact of the owner's objectives and project constraints on the selection of a PDS, when they change along with the market situation. The same concerns situations where certain types of projects are launched mainly in certain economic and market situations (eg, large commercial projects utilising CM in an upswing or boom).

The appropriateness of CM in a boom is due to the breakdown of the project into numerous small works and the use of a target-cost contract. CC, again, does not involve a breakdown, which, for its part, makes it suitable for a recession. As regards SC, its advantageousness in relation to CC clearly improves as the market heats up, but it does not compare to CM. Thus, solely based on the data, SC's relative position among the various PDSs does not change in the big picture.

The position of DB is more challenging. The data seem to suggest that it is first and foremost a PDS for booms while some statements seem to contradict that idea. This may also be due to the different sub-types of DB. The same rules do not apply in the case of a laborious design proposal competition for a technically demanding facility as in negotiations for a simpler building, for instance. There is not just one DB, and the logic is likely to be different for different construction sectors and applications. Sub-types of DB exist as do sub-types of CM in reference to construction management for fee and at risk.

All in all, the study indicates that the market situation has an impact on the use of different PDSs and, therefore, PDS selection would benefit from the incorporation of the impact of the market situation into the selection systems. However, that requires definition of PDS sub-types if a more sophisticated application is desired. Further studies are naturally needed since the study at hand is just an exploratory opening on the topic. Yet, the study paves the way by revealing market situation-related factors that have an impact on PDS selection. These factors are mainly related to the cost efficiency of the arrangement.

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APPENDIX 1

Formulas for the calculation of second order partial correlations

The correlation coefficient (r) for the two variables, x and y in the example, over n observations is the following:

$$r_{xy} = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \cdot \sum_{i=1}^{n} y_i}{\sqrt{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right] \cdot \left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \quad (1)$$

The first order partial correlation calculated from (zero order) correlations given by Formula 1 offers a means to eliminate the impact of one variable (z) on the relationship of the other two (x and y):

$$r_{xy\cdot z} = \frac{r_{xy} - r_{xz} r_{yz}}{\sqrt{1 - r_{xz}^2} \cdot \sqrt{1 - r_{yz}^2}} \quad (2)$$

In such a case, the correlation coefficient is represented by $r_{xy\cdot z}$. The subscripts of correlation coefficients in Formula 2 indicate the variables whose mutual correlation is in question, which means that correlations are calculated for all pairs of variables x, y and z by Formula 1 by changing the variables as appropriate.

The *second order partial correlation* between x and y, where the impacts of two intervening variables (z, t) are eliminated, can be derived from Formula 3:

$$r_{xy\cdot zt} = \frac{r_{xy\cdot z} - r_{xt\cdot z} r_{yt\cdot z}}{\sqrt{1 - r_{xt\cdot z}^2} \cdot \sqrt{1 - r_{yt\cdot z}^2}} \quad (3)$$

This, again, requires the calculation of numerous other correlation coefficients, direct and first order ones, but the logic is similar to that already expressed.