Assessing Construction Supply Chains: Search for the Best Configuration

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Abstract

Construction supply chains are usually one-off combinations of cooperating business entities. With many potential partners to choose from, and numerous options of transport means and routes, arranging the supply chain for a project is not an easy task. Its implications are costs, time, and quality. To facilitate the decision making process, the authors put forward a method of assessing options of supply chain configuration. The method is based on a modified quantitative approach to SWOT (Strengths, Weaknesses, Opportunities and Threats). To illustrate the idea, the method was applied to a simplified case based on a real-life project. Though the method does not automatically respond to changes and risks that occur as the project develops, it is considered useful at the early planning stage as an element of early strategic analysis: not only to pick the best of available options, but to plan logistic management actions.

Keywords: option selection, quantitative SWOT, supply chain.

Introduction

Supply Chain Management (SCM) is one of the developing concepts in construction project management. Apart from analysing the aspect of project participants' logistic processes to add value and increase efficiency, it promotes a philosophy of "common goal" and the focus on the end-user needs (Isatto, 2005), as cooperation is claimed to maximise the reward of all businesses within the supply network. SCM derives from all management approaches and utilizes any tool invented to improve business process integration (Vrijhoef and Koskela, 1999; Sobotka and Jaśkowski, 2009). Therefore, the supply chain is considered to be not only a set of related suppliers, intermediaries, and customers, but a system of processes and relationships that bind organisations in their efforts to supply, produce and distribute all that is necessary (materials, equipment, energy, information, funds etc.) to add value at each stage of the process and provide output that satisfies the final customer (European Committee, 1997). In the case of construction projects, this output is either an engineered-to order, operational built facility, or an engineered-to-order service provided by the operator on the basis of the built facility.

Strategically, the supply chain configuration (establishing the set of participants and the type of relationships binding them) is decided early at the project preparation stage. Its framework is defined by the project's procurement system and procedures of selecting the key project participants: the design team and the contractors. This stage defines the

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responsibilities for the further development of the project's supply chain and related logistic system. Quite often, the process of designing the construction project's networks of suppliers and subcontractors, establishing the relationships between them and directing flows of physical resources and information becomes a full responsibility and risk of the project participants hired by the client. The time for their strategic planning in this respect is limited by the time the client allows for preparing bids. Their decisions are constrained by their contracts with the client. There is little space for testing and tuning the supply system. Quite often, at the moment of contract signing, only a few members of the supply chain can be treated as sure to participate, and the remaining ones are to be found as the project is under way. This way the supply chain configuration decisions come from the strategic level down to tactical and operational levels.

The paper focuses on the strategic decisions in designing the project's logistics system within the supply chain, in particular, the supply logistics subsystem of the construction phase. The systems can be roughly divided into three types: dispersed – managed independently by project participants, centralized – controlled by the main project participant that takes full responsibility of project delivery, and subcontracted – also centralized but managed by a specialized link of the supply chain to allow others to focus on their core competences rather than on synchronizing flows between their partners. Such decision problems occur also in manufacturing (Xu and Xia, 2008). Strategic decisions in this respect have a profound impact on efficiency of manufacturing organizations as well as project efficiency: Bertelsen and Koskela (2002), having conducted surveys in Denmark, found that careless approach to project logistics increased project cost and time by about 10%. Other authors argue for this 10% being an underestimation (O'Brien, 1999).

To facilitate the decision making process, the authors put forward a method of assessing options of supply chain configuration. The method is based on a modified quantitative approach to SWOT (Strengths, Weaknesses, Opportunities and Threats).

Construction Supply Chain Configuration

Construction Supply Chain Features

The manager of the construction supply chain needs to address the traditionally adversarial relationships between the supply chain links (Bygballe et al., 2010, Eriksson, 2015). They arise from dividing responsibilities for planning, design and construction works (used in most popular procurement systems) together with observed poor communication between the project participants (Mello, 2015). The tradition of competitive procurement with its one-off transaction approach (Cox *et al.*, 2006, Bankvall *et al.*, 2010) adds to the problem. As the cooperation in the construction supply chain is not meant to be long-lasting, the full commitment of its members is not guaranteed and opportunism very likely (Isatto and Formoso, 2011, Meng, 2012).

More potential problems in managing the construction supply chains arise from uncertainty. The final product's configuration evolves over the project life cycle (Kristianto et al., 2015). Moreover, construction projects are generally prone to risks, starting from the impact of adverse weather to the effects of relying on impromptu selected suppliers. Thus, changes and disturbances are likely to occur, and the supply chain must keep answering the project needs.

Another issue is the variety and quantity of resources the construction project consumes. Many of them are unique, engineered-to-order and one-off. Undoubtedly, many construction-specific resources are widely available (e.g. typical machines, rough materials), but the sheer volume to be delivered to the construction site within short time of construction is a challenge to the organizations involved in provision, transportation and processing. From the point of the supply chain members, the location of the construction site is random. Quite often, there is no adequate transport infrastructure – thus the effort of building a short-term, unrepeatable, reliable logistic system for a one-time venture is huge.

The above mentioned features of construction supply chains make them more difficult to manage than the manufacturing supply chains. The latter have a perspective of long-term cooperation. Once created, they operate in the same configuration for some time providing opportunity for continuous improvement of the system to the benefit of all parties involved, and for developing the logistic infrastructure to serve for a long time. Thus the tools and methods that are state-of-the-art in the manufacturing supply chain management are not directly transferable to construction. The models well proven in mass production with repetitive processes do not suit the needs of the one-off project environment. However, the general concept of SCM is argued to be implementable to construction. O'Brien (1999) states that prerequisites for implementing SCM to construction are, among others:

- More precise and reliable modelling of the construction to directly account for processes entrusted to subcontractors and suppliers – such integrated modeling is to enable the planners to analyse the impact of project decisions on costs and other project aspects in every point of the supply chain,
- Developing rules for designing construction supply chains and measuring their performance.

Vrijhoef and Koskela (2000) identified four key tasks in the practice of construction supply chain management:

- adjusting supplies to the on-site processes; this is to assure smooth progress of construction works and save on their time and cost; the focus is on reliability of material flows and fostering relationships between the direct suppliers and the construction site, and the responsibility is taken by the contractor who manages the on-site processes;
- improving efficiency of flows within the supply chain to reduce costs of deliveries (e.g. by reducing delivery time) and cost of inventory; the suppliers may affect the organization of deliveries, the structure of the supply chain, delivery timing etc.;
- conducting some construction processes off-site – so entrusting them to other links of the supply chain; this is to allow concurrent delivery of some processes that would not be possible due to on-site constraints (e.g. not enough space); this is aimed at reducing construction time and/or cost, and can be initiated by the contractors as well as by the suppliers;
- integration of the supply chain management and the management of the on-site production, so treating the construction site as one of the links of the integrated supply chain; this is a task for the client as well as the suppliers and contractors.

Configuration and development of a construction supply chain and related logistic system is affected by many factors, for instance procurement path preferences, construction methods chosen by the design team, project scope, or the planning team's preferences and skills in breaking down the scope into work packages to be contracted out. Nevertheless, it is based on a certain framework, a set of general, strategic-level assumptions on how to distribute tasks and risk, what type of suppliers to use, and how to select them. Kumaraswamy et al. (2000) argue that methodologies and decisions on the supply chain members selection are critical, both at the upstream formulation of procurement and operational systems (including the supply logistics system), as well as the downstream selection of particular project participants. The section to follow focuses on the problem of selecting the general structure of logistic system on the strategic level, and does not investigate into the tactics of evaluation, selection and negotiations with a particular supplier.

Selecting the Logistic System to Serve Construction Works

As there are many procurement systems defining the scope of project participants' tasks, risks and responsibilities, it is impossible to look for the best configuration of a logistic system to serve the construction phase in abstraction from them. Moreover, the natural evolution of the project supply chain mentioned in the previous sections may prevent the planners from sticking to one rigid structure of logistic system from construction start to completion. Generally, there are four models of supplying construction projects:

- dispersed – the project is supplied by a number of independent supply chains serving particular independent contractors or subcontractors; selection of suppliers is at the risk and responsibility of contractors,
- centralized – the project is supplied by a supply chain managed by the general contractor or other entity that manages all works,
- subcontracted – the project supplies are managed by one logistic organization hired or created in this purpose,
- combination of the above.

The dispersed model can be applied to any project. It is rational only if contractors take full risk of delivery failures, but may negatively affect coordination of works and cause conflict of interests if supplies cumulate overloading the site infrastructure's capabilities of handling inventory. Centralized model may be advantageous in projects led by a general contractor capable of providing logistic services, managing the work of subcontractors, and benefiting from economies of scale and coordination of deliveries. Like subcontracted model, it offers the most control power, crucial in work-intensive projects with short makespan, limited site area and difficult access to the site.

The process of shaping the supply chains to serve the construction works (with focus on material and component supplies) consists in selecting delivery models, sources, and transport modes for each link of the supply chain – with consideration to the impact on the on-site activities (construction/production methods, make or buy decisions). There are many options of step-by-step conversion of resources that finally come to the construction site, so the processes that make raw materials turn into components of the built facility. They can be conducted by different sets of organizations using various methods, sources and substrates (Tennant and Fernie, 2012). The key problem is to find the best configuration of the supply chain, so to optimize the basic parameters that characterize the efficiency and effectiveness of supply chain operations (Li and Womer, 2008). This optimization cannot be done without cultivating good relationships between supply chain links and providing incentives for integration (Vrijhoef and Koskela, 1999, Bygballe *et al.*, 2010). The welcome effects of cooperation in the supply chains would be incorporating the on-site production processes into the integrated supply chain for better control:

- Synchronized deliveries and construction processes (reduction of non-value-added handling operations and disturbance to workflow on site – so at the destination point)
- Smoothed flows across the supply chain at large (overall reduction of handling cost)
- Entrusting some processes typically done on site to the suppliers, so that they can be conducted in controllable factory environment while maintaining full control over cost, quality, and schedule (prefabrication).

Selection of a logistic system configuration depends on many SC and project specific factors such as the experience of the SC practitioners, capacities of the firms and requirements of the project (Polat and Ballard, 2003). As the main purpose of the supply chain is to maximize the operational efficiency, profitability and competitive advantage of the participating firms by meeting the customer's requirements in a better way, the performance of the supply chain should be also measured in part by using metrics such as time, cost and quality. According to Arbulu and Tommelein (2002) the selection of logistic system configuration must take into account the supply chain metrics of the system performance in terms of lead time, value-added-time, information flow and cost. Some data for these metrics may be readily available whereas other data is more difficult to obtain or to predict at the stage of selecting the SC configuration – such as cost data. Defining a set of factors influencing these metrics, as proposed by Xu and Xia (2008) for transaction cost to support logistics model selection .

Arbulu and Tommelein (2002) argue that capabilities, capacity and strategic corporate goals of each of the companies involved in supply chain, as well as industry trends and the current and forecast market situation are equally important. The supply chain shaping decisions cannot be done without deep knowledge on the market and anticipations on its development: accessibility of locally and globally available materials and substitutes, types of providers and their capabilities, funding sources, payment routines, preferred modes of communication, willingness to cooperate, etc. (Sobotka, 2010). Thus, a supply chain of certain design, by its nature, has a foreseeable impact on the project time, cost and quality, but this cannot be judged without consideration to the external surrounding: different types of supply chain are not likely to react to the changes of environment in the same way. While deciding on a certain configuration of the supply system, one should account for its internal and external determinants.

The set of applicable project logistic system's assessment criteria on the strategic level is therefore twofold: it should cover the qualities inherent in the system, and the system's answer to the outer environment. To select the best option of supply system against its application to a particular case and in particular circumstances, the authors consider a modification of the Strengths-Weaknesses-Opportunities-Threats analysis (SWOT).

Approach to Assessing Project Logistic System Options

The SWOT analysis is a well established simple tool used to organize information on internal and external, favourable and unfavourable factors likely to affect a business. It is often used for rough qualitative comparison of chances of success of optional strategic plans. The method does not enable the user to precisely describe a complex problem: basing on the incomplete list of considered positive and negative project/business qualities and perceived supportive and adverse effect of the environment may be not enough provide reliable guidelines on the businesses' likely response to the external conditions, but it nevertheless helps to uncover opportunities the organization is likely to be able to exploit. SWOT is often used in combination with other methods, including quantitative ones that provide the user with more tangible measures (Zavadskas et al., 2011).

The authors propose to apply a quantitative modification of SWOT analysis to assess optional proposals of a type of supply chain organization to supply a construction project with materials. The method is a development of a method by Chang and Huang (2006). It allocates the considered strategic options into a four-quadrant Grand Strategy Matrix (GSM). The strategy options to be compared, A_1, A_2, ...,A_i,..., A_n are represented by points in a two-dimensional space whose position is described by coordinates: one represents the assessment of the environment's impact, the other – assessment of the strategy's potential. The assessment is conducted according to the following procedure:

- Prepare the sets of criteria: K_E for assessing the environment's impact, and for assessing the internal potential of an option, K_I; the criteria are case-specific and the set worth considering in the analysis can be defined by experts.
- Define the relative importance (weights w_j), of the above criteria $k_j \in K_E \cup K_I$, separately for the assessment of the environment impact on each option and the option's internal potential; as in the example provided in the section to follow, this can be based on expert opinions and AHP analysis (Saaty, 2004); if opinions of many experts are to be used to avoid bias, they can be aggregated by means of methods applicable for group decision analysis (e.g. modified AHP for group decision environment or Delphi).
- Quantitatively assess the strategy options. Each option $A_i, i = 1, 2, ..., \mathrm{n}$ is to be assigned a score s_{ij} with respect to each criterion $k_j \in K_E \cup K_I$ in a 0 to 1 scale with 0.1 interval. All criteria should be of stimulant nature, thus the score $s_{ij} = 0$ means that a particular strategy is seriously weak in terms of, or seriously threatened by, the considered criterion k_j, and $s_{ij} = 1$ indicates the opposite. A score of 0.5 means that the criterion is neither strength nor weakness of the option (or the criterion does not pose any threat, but also does not promote the analysed option). Then, synthetic scores that define the coordinates of the option's position in the environment/potential space are to be calculated as a sum of weighted scores:

$$S_i^E = \sum_{k_j \in K_E} s_{ij} \cdot w_j, \, i = 1, 2, ..., n, \tag{1}$$

$$S_i^I = \sum_{k_j \in K_I} s_{ij} \cdot w_j, \, i = 1, 2, ..., n. \tag{2}$$

- The scores are to be given by an expert. If one expert was not considered reliable, a number of experts should be asked for opinions, and aggregation of the opinions to provide averaged scores conducted by methods applicable for group decision analysis as above.
- Present the results in the Grant Strategy Matrix (GSM). Then calculate a final score for each option as the distance between the point of the option's location and the ideal point of most favourable environment's impact and highest potential (its coordinates are (1, 1)) using the formula:

$$S_i = \sqrt{\left(1 - S_i^E\right)^2 + \left(1 - S_i^I\right)^2}, \, i = 1, 2, ..., n. \tag{3}$$

Example

The following case serves as illustration of the application of the method. The analysed problem was selection of a reasonable configuration of a materials supply system for finishing and decoration works for a complex construction project – a large shopping mall with entertainment centre located in Warsaw, Poland. The total volume of buildings was over 200,000 m3. The project was delivered by a main contractor that disposed of certain number of own workforce, but subcontracted most work packages. The general contractor was also partly involved in the design phase: following the scheme design by the separate entity, they were to provide some design optimization and working drawings (however, this did not concern the finishing works). Location of the project was a densely populated and traffic-congested centre of the capital city of Poland (1.7 million inhabitants), which involved restrictions on delivery times and noise emission. Due to the size of the building, no storage area outside it, and limited possibilities of storing supplies inside the building, the deliveries had to be organized in just-in-time manner. The stage of finishing and decoration works included fixtures and fittings in a large number of areas differing in function, handling masses of fragile and expensive materials, removing huge quantities of packaging waste, and coordinating several thousand of construction workers. Organization of these works required that the building was divided into distinguishable zones, each equipped with signage indicating egress and exit routes, level and room identification. Each person present on site needed to be authorized to enter and equipped with identification badge.

The input for the SWOT analysis was based on opinions of one expert: a person involved in the analysed project (the general contractor's project manager), who was interviewed by the end of the project. The opinions were collected ex-post which surely affected the expert's opinions; however, the case serves as an illustration of the method.

For this stage of works, three strategies for supply chain configuration were considered: A_1 – a dispersed logistic system, where the main contractor and subcontractors were to source themselves independently, A_2 – a logistic service provider to manage resource needs of all working teams, A_3 – a centralized supply system provided by the general contractor.

Tables 1 and 2 list the criteria related to the strategies' inherent strengths and weaknesses, and the environment-related threats and opportunities, respectively. They were prompted by the interviewed expert and the literature on the subject (Sobotka, 2010).

Table 1. Strengths and weaknesses: criteria, weights and scores of the strategies' qualities

No.	**Criterion k_j**	**Weight w_j**	**Score s_{ij}**		
			A_1	A_2	A_3
1	Efficient transport organization	0.05908	0.1	0.9	0.4
2	Possibility of just-in-time deliveries	0.16850	0.5	1.0	0.6
3	Reduced risk of material shortage	0.26464	0.3	0.9	0.6
4	Possibility of extra deliveries in case of schedule changes	0.02612	0.4	0.9	0.6
5	Using economies of scale	0.13966	0.1	1.0	0.5
6	Savings on storage infrastructure costs	0.07604	0.1	0.9	0.4
7	Number of material handling operations	0.07584	0.3	0.7	0.5
8	Reduced pollution	0.02083	0.3	0.9	0.6
9	Chance of on-time deliveries	0.13535	0.5	0.9	0.7
10	Reduced ordering cost	0.03394	0.6	0.7	0.8
Synthetic score for strengths and weaknesses S_i^I			0.31861	0.90886	0.57175

Table 2. Opportunities and threats: criteria, weights and scores of the external environment

No.	Criterion k_j	Weight w_j	Score s_{ij}		
			A_1	A_2	A_3
1	Technological progress (need to adapt and invest)	0.04161	0.2	0.4	0.2
2	Growing bargaining power of the suppliers	0.28819	0.1	0.4	0.2
3	Growing environment protection requirements	0.05430	0.3	0.4	0.3
4	Growing material prices	0.07529	0.1	0.7	0.3
5	Growing number of manufacturers in the market	0.06512	0.4	0.8	0.8
6	Material shortages due to global demand fluctuations	0.23959	0.2	0.7	0.4
7	Growing popularity of subcontracted logistics	0.23589	0.2	1.0	0.6
Synthetic score for opportunities and threats S_i^E			0.18210	0.66204	0.39430

The weights of the criteria in the "strengths and weaknesses" represent relative importance of the considered quality according to the interviewed expert. The weights of the "opportunities and threats" criteria were related with the likelihood of their occurrence perceived by him. The values of the weights were calculated according to pair-wise comparisons by means of AHP (Saaty, 2004); the process is not explained in detail as it is not the key feature of the presented approach and the results cannot be generalized. The scores sij for each analysed option were given directly by the expert – as one expert was involved, a simple rating scale of 0-1 was considered sufficient.

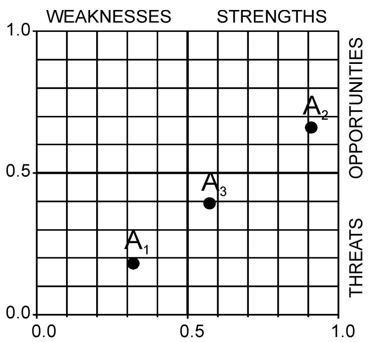

Figure 2. Grant Strategy Matrix and the analysed strategy options

The final scores for the strategy options, calculated by to Formula (3), are: S_1 = 1.0645, S_2 = 0.3501, S_3 = 0.7418. Figure 2 shows the position of each strategy in the GSM. Strategy 2 (subcontracted logistic service) is the closest to the ideal point. Its qualities are: domination of strengths over weaknesses and opportunities over threats. Thus, the maxi-maxi strategy is most appropriate: the strategy's advantages can be used efficiently under favourable external conditions. The second-best strategy is the centralized supply system managed by the main contractor (A_3). Here, the advisable strategy is making the best of its strengths to make up for the unfavourable impact of the environment. The dispersed system is assessed as the worst choice – as many subcontractors are at work at the same time, disturbance caused by uncoordinated deliveries, difficulty in finding independent storage space on the congested site and no chance of profiting from the economies of bulk purchases make the weaknesses prevail, and there are practically no external opportunities to explore. Interestingly, the project actually used the A_3 option. According to the interviewed project manager, this was because the general contractor could not find a suitable logistic organization within reasonable time, and experienced staff was available.

Conclusions

The supply chain management methodology used in manufacturing industry suggests the following steps to perfecting the organization's performance: assessing the supply chain, reconfiguring the supply chain's structure, coordinating the supply chain according to the new configuration, and continuously improving it. This kind of continuous and long-term improvement of the supply chain is out of question in construction, because each project means a new supply chain: cooperation is naturally short-term and the relations between firms are typically maintained only for the duration of the project. The consequence is lack of partnering and adversarial relationships. Therefore, in the construction project environment there is a call for decision support tools to facilitate getting the supply chain configuration right the first time. The results of analysis of a case presented in the paper cannot be generalized to any construction project, but reflect current practices of supply management for complex projects. Outsourcing the project's logistic services to professional organizations becomes an available and profitable option that allows the contractors, construction managers and clients to focus on their core competencies. Nevertheless, the markets develop dynamically, and logistic strategies of construction projects need to be flexible to exploit chances offered by this development.

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