Managing the Construction Supply Chain by Simulation

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1. Introduction

This paper is an abbreviated version of the author's licentiate thesis [1] that surveys recent theories of procurement, logistics, supplier development and supply chain management, and presents 19 recent case studies, of which 4 by the author. The thesis reviews current simulation methods, tools and applications, and presents 4 recent cases on simulation of construction operations and projects. An overview of simulation software is given. In the computational phase of the study, a simulation model of the constructional supply chain is designed, built, calibrated, tested and validated. An off-the-shelf, affordable PC-based software package is used for the simulation. The resulting "Chainsim" model is used for production runs to obtain estimates on supply chain costs and project completion times.

2. Supply chain methods in construction practice

Supply Chain Management (SCM) is a 1990's addition to the logistical toolbox for construction procurement. SCM in general terms is well described by Schary & Skjött-Larsen [2] as follows: "The objective of supply chain management is to minimize the chain members' total cost of manufacturing, materials, labor, transportation, inventory and information, for all parties concerned. The savings will be shared." In practice, it requires the partners in the supply chain to open up their books to each other, to compare the costs at each stage in the chain, and to strive jointly towards a minimum cost for the whole chain, while keeping an acceptable level of service.

Cases of using SCM in construction are few, and "the jury is out" on the results achieved. Two readable cases can be mentioned: A study of the supply of precast elements to apartment buildings in Finland by Laitinen [3] and a study of unit deliveries to condo housing in Norway, by O'Brien [4]. A procurement method in construction that resembles SCM is called "supplier development" in Finland, and "partnering" by the CII [5] in the USA. Särkilahti presents some useful cases from practice, such as interior fixtures, in his recent licentiate thesis [6].

3. Simulation methods and tools for construction practice

3.1 Simulation overview

A simulation is a description or enactment of a real-life process. Simulations are used to describe complicated processes, where the relations are difficult to define causally, or an analytic model would be too difficult to solve. The simulation model often has a number of simultaneous variables, and a multitude of parameters. A simulation model does not optimize, but by performing a number of trial runs and comparing the results, an estimate of the optimum may be reached.

3.2 Simulation methods

The use of simulation methods for construction applications is a rather recent phenomenon, although the milestone Ph.D. thesis of D.W. Halpin [7] was published as early as 1973. The first more widely published works on the subject are from the late 1980's and early 1990's. The applications can be divided in two categories: Process simulations and project simulations.

Process simulations typically concern a single or a handful of activities, such as earth moving, concrete pouring, or the asphalt paving investigated by Halpin & Woodhead [8] and apartment renovation by Ristikartano [9]. Process simulations usually involve cyclical (repetitive) operations. **Project simulations** encompass a whole construction project, or at least a major part of it. Recent simulations include a 3-story apartment building by Vehkaoja [10], a 3-span bridge by Sawhney et al. [11] and a large basement by Ng et al. [12]. These studies and others are reviewed in the thesis [1].

3.3 Tools for mathematical simulation

Mathematical models are best solved by computer methods, using built-in features for clock time, randomizing, probability distributions, queue content, etc. Computer modeling may be performed by one-off, custom-tailored software, or by using readily available, "off-the-shelf" software.

Custom software may be implemented in a general-purpose programming language such as Pascal, Visual Basic or C++, or special simulation languages such as Simscript and Slamsystem (as used by Sawhney & AbouRizk [11]). **Off-the-shelf software** for simulation, such as Simul-8 [13], is nowadays available for use on standard-specification personal computers, at affordable prices. High-end packages such as PowerSim [14], as used by Ng et al [12], are available for the demanding user with a more flexible budget. Software is further reviewed in the author's thesis [1].

4. Building the "Chainsim" simulation model

4.1 Description of the problem to be modeled

The construction project selected for the modeling was taken from the thesis on scheduling by Niiranen [14]. It was chosen to represent a large standard project allowing cyclical activities. The project is an office block with the following features:

Table 1. Features of the simulated project.

Feature	Amount	Unit	Remark
Floor area	4.000	m2	
Blocks (shafts)	2	pcs	
Stories (height)	3+2	pcs	1 shaft of 3 stories, 1 shaft of 2 stories
Subcontracts	6	pcs	Foundations, structure, cladding, partitions, HVAC, finishing (originals by Niiranen)

Materials	6 1600	types tons	Piles, precast, windows, bricks, locks, tiles (groupings & estimate by author)
Project duration	200	workdays	
Contract sum	10.000	tmk	Estimate by the author

The system to be simulated is functionally divided into seven elements. The **site office,** handles project control and procurement. The **construction site** receives and handles the incoming materials and installs them as a part of the works. The **design office** produces the working drawings of the subcontracts. The **subcontractors' office** houses the six subcontractors who each procure their own materials from the factories and dispatch their own crews to the site. The six **factories** produce their materials for inventory, and upon receipt of delivery requests will dispatch the materials to site or the **external market.** A **transport company** picks up the material at the factory, loads it onto the truck, transports it to site and unloads it there.

4.2 Description of the quantities to be estimated by simulating

When the project starts, certain matters are **fixed** by the contract. These are contract duration, types and amounts of materials required at site and the fixed contract sum to be paid for completing the project within the contract duration.

The major **inputs** for **project control** are timing of procurement (when to procure drawings and subcontracts) and timing of site access (when to let the crews on site). The major inputs for **supply control** are batch size (how much to order), refill level (how soon to order the next batch), storage capacity on site and at factory and the number of trucks serving the site. The major inputs for **resource control** are the size of crews for each installation and the number of workers at each factory.

The major **outputs** of the simulation are an estimate of **project completion** (number of workdays from start-up) and the estimated **supply-chain costs.** The cost is calculated separately for each participant in the supply chain, using material costs, transport costs, installation costs and handling costs, and then added up. Details of the costing model can be found in the original thesis [1]. Other useful outputs are **resource loadings, site arrival and exit times** and **average inventory sizes.** By analyzing these outputs, the timing and resources of the project may be adjusted to achieve faster completion or lower cost. The **lowest-cost strategy** that ensures on-time completion will be recommended for application. The thesis includes a **"hardhat overview"** of the simulation model, using construction language, while omitting all mathematical and stochastic mumbo-jumbo.

4.4 Modeling principles and tools used

Modeling principles: The model is dynamic (evolving over time) as time is an important element in construction. The model keeps time in hours. The model is discrete, as both materials and labor can be measured in discrete chunks such as units and workers. The model is stochastic because there is a certain element of randomness and risk in construction; site progress cannot be exactly forecast in advance. The model is not interactive: A simulation runs by itself until the simulation time is up, and parameters are only adjustable in steps between trials.

The **economic model** is designed according to Supply Chain Management principles, with due consideration to construction practice and software limitations. The revenues are fixed by the Contract Sum, being 10000 tmk (10 million FIM). The model does not consider possible extra work, claims, bonuses etc. The cost categories are material costs, human resource costs (site management, factory manufacturing, trucker time charges, site installation), plant resource costs (truck time charges), and inventory holding costs. The optimal strategy for the supply chain is the one that creates the lowest total costs for the whole chain.

The general-purpose, budget-priced Simul-8 **software** and profit module by Visual Thinking Ltd. [13] was used for the simulation. The program was run on a standard portable laptop PC with 32 MB RAM and 250 MHz processor. A simulation of a 200-day project was performed in less than a minute. Doing a series of 100 random runs as required for statistical validity required 15-20 minutes. Software and hardware are presented in more detail in the appendix of the thesis [1].

4.6 Building the model
The model was built rather quickly, in the user-friendly graphic format of Simul-8, using the "code-and-fix" process. It was developed, debugged and calibrated using the "daily build" principle. For validation, the methods by Banks & Gibson [16] were used. A list of extreme cases was made, and the expected result listed. The model was then run, and the result compared to expectations. After some adjustment of material volumes and productivity parameters, the model was ready for production runs.

5. Using "Chainsim" for production runs

5.1 Strategy and methodology for the production runs
The decision process of the supply chain participants was simulated, as follows:
I. BaseCase: The first round simulated the pre-contract planning phase, where a "good enough" estimate is patched together, without much effort.
II. LowCases: The second round simulated the incommunicado "solo flying" of each participant, looking at his own map of familiar territory. "FactLow" is the case giving the lowest cost for manufacturing, "TransLow" the low-cost solution for the transport company, and "ConLow" the contractor's low-cost setup.
III. ValueMax: The third round simulated the information sharing method of SCM, when partners glue together an overview map from their own bits of mosaic, and together strive to find the lowest-cost solution.

5.2 Results of production runs
Table 2. Numerical comparison of solutions to the Chainsim model.

Rank:	Solution:	Duration:	Special features:
I.	ValueMax	177 days	Full truckload, 2 trucks, lean crew, early start
II.	ConLow	177 days	Half truckload, 2 trucks, lean crew, early start
III.	TransLow	188 days	Full truckload, 1 truck
IV.	BaseCase	187 days	Half truckload, 2 trucks, regular crew, regular start
V.	FactLow	187 days	Half truckload, minimum factory storage

Rank:	Solution:	Total cost:	Net savings	Value-added:	V.A. (%)
I.	ValueMax	8497 tmk	+ 320 tmk	+ 1503 tmk	15.0 %
II.	ConLow	8652 tmk	+ 167 tmk	+ 1350 tmk	13.5 %
III.	TransLow	8688 tmk	+ 129 tmk	+ 1312 tmk	13.1 %
IV.	BaseCase	8817 tmk	0	+ 1283 tmk	12.8 %
V.	FactLow	8974 tmk	- 157 tmk	+ 1036 tmk	10.4 %

c. Discussion of summary results
The results show that application of the Value Chain method obtained savings of 320 tmk (3.2 % of total project cost) compared to the pre-contract BaseCase solution. Best efforts by the participants working singly produced net savings from +167 to -157 tmk on either side of the BaseCase. The project duration was also cut by 10 days, a reduction of 5.3 % of the BaseCase duration, and of 5.0 % of the contract duration.

6. Key findings and recommendations

6.1 Key findings on simulation in construction
On the basis of the work performed, the author has reached the following conclusions: Simulation is educational, but time-consuming. Simulation works best for cyclical operations. Parametrical data is scarce, especially on stochastic variations. Software could be improved. The viewpoints are further justified in the thesis original.

6.2 Recommendations on simulation in construction
The **simulation** method can be recommended for firms engaged in construction of **repetitive projects,** especially **large projects** where sufficient funds for planning are available. This also applies to projects in **distant locations**, where solid preparations are of the essence Simulations could also be applied to **educational, promotional** or **legal** purposes.

7. Discussion of tools and methods used

7.1 Time used for analysis
The **time** spent climbing the learning curve of simulation was estimated as follows:
Table 3. Estimates of time required for simulation of construction project.

Stage	**Novice starting from scratch**	**Experienced user doing a repeat project of similar style**
Learning simulation methods	6-12 weeks	Updating incl. in model building
Learning the software	2 - 4 weeks	Updating incl. in model building
Collecting data	2-4 weeks	2-5 days (updating database)
Building and testing the model	2-8 weeks	2-5 days (incl. discussions with client)
Running the model and analyzing the results	1-2 weeks	2-10 days (longer if logic is faulty or data missing)
Findings & recommendations	2-3 days	1-2 days (brief action report for client)
Total cycle time	3 - 6 months	2-4 weeks

7.2. Costs of simulation
The main cost is the investment in time for learning a new methodology. The investments in software are small compared to that, and the hardware is probably available anyway. It pays to evaluate the software and choose the one that has the required features for the application. The program should be easy to learn (which can be judged from the interface and the manual) but more importantly it should be fast for productive work (which is hard to judge before purchasing). Ask for references in your field, and interview the users.

7.3. Benefits achieved

The main benefits accrue from better scheduling and use of resources. Improved scheduling and procurement means improved control and lower inventory costs. Starting with the correct amount of resources may avoid crash-up costs in getting extra crews or equipment in a hurry, often at inflated prices. The more distant the site is, and the more expensive the equipment, the bigger the potential benefits. In our test case, the simulation brought savings of 350 tmk, or 3.5 % of the contract sum, i.e. a substantial magnitude. The 10 guidelines of Banks & Gibson [16] may be used to evaluate whether a simulation is appropriate. A thorough discussion on these lines is included in the original thesis work [1].

In closing, the author sincerely hopes that this work will give a contribution to the international debate on supply principles and simulation in the construction industry.

Espoo, February 10, 2001. Henry Ericsson

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