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Libera Università di Bolzano
Università Liedia de Bulsan

Master in Industrial Mechanical Engineering – LM 33

Project report

Simulation of Real Time Capability in Production Planning

A study of a real-time planning and measuring approach applied in the construction industry, with the goal of reducing the average content as well as the average stay-time of material in the buffers on the construction sites.

Florian Morandell 11903

Mario Goldin 7026

Supervisors:

Dr.-Ing. Patrick Dallasega
Dr.-Ing. Erwin Rauch

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1. Introduction and objective of the work

The objective of this project is to study the effects of a nearly real-time capable production planning in Engineer-to-Order environment of small and medium sized enterprises (SMEs). For this reasons a simulation in Flexsim was developed by the students to simulate the effects using a traditional push-oriented and a nearly real-time pull oriented production planning approach in a project of the company Frener & Reifer GmbH.

2. State of the art and research

2.1 Research methodology for literature review

We utilized the Systematic Literature Review (SLR) methodology to review published works systematically and obtain a balanced and objective summary of the current state and future potential about Push and Pull Strategies in construction supply chains. SLR is a method-driven, transparent and replicable approach for evaluating and interpreting all available research relevant to a particular question, topic or phenomenon of interest. This method minimizes bias through exhaustive literature searches of published and unpublished studies and provides an audit trail of reviewers' decisions, procedures and conclusions. SLRs are powerful instruments to evaluate published work in a scientific field; a property that other methods, for instance, citation based approaches, lack. We applied the often-recommended three-step approach in conducting our SLR. This involved a preparation stage where we planned how we want to do our literature review by defining the research questions, developing and validate the Review Protocol. The second step was the operative part of the review once the paper where identified. Analyzing and extracting data is a port of it. The last of the three step was the writing of the report and the final validation.

2.1.1 Establishing research objectives

In our study, we aimed to understand the effects of a Pull approach in construction projects, by using the Discrete Event Simulation method. We analysed and compared the on and off-site activities between the classical Push with the Pull Approach. In addition, we extend the Pull Approach including a real time feedback loop, to understand how this would affect the output.
Conducting the research on the literature review, two main parts were defined. Firstly, to what extent simulation studies have been used in construction projects especially for deliveries between on and off-site activities. Secondly, which parameters were used to model the uncertainty of on-site activities to build our simulation as realistically as possible.

2.1.2 Conceptual boundaries

To specify the conceptual boundaries of our research, we searched for the terms "Discrete Event Simulation", "Supply chain" and "Construction" in publications relating to engineering in the SCOPUS library.

Detailed search string:

(TITLE-ABS-KEY ("Discrete Event Simulation") AND TITLE-ABS-KEY ("Supply chain") AND TITLE-ABS-KEY (construction))

2.1.3 Inclusion and exclusion criteria

To find the related works for our analysis we decided the following inclusion criteria:

1) no limitation on publication date;
2) no limitation on used Language;

The result of the publication research in SCOPUS was 34 documents. We eliminated 3 articles, because there was no indication about the author nor about the title. Finally we got 31 documents to analyse in detail.

2.1.4 Screening of search results

As such, we developed the following criteria to help us decide which studies to include:

1) strictly related to construction industry;
2) strictly related to supply chain management;
3) studies about workflow variability on construction sites;

By reading the title and abstract of the articles, we manually excluded all studies not aligned to these criteria. We identified 14 papers that focused on our topic. We conducted backward and forward searches to ensure we did not miss relevant work. This method allowed us to rely not only on our keyword search but also to check the reference list of relevant papers for other relevant publications. We identified 30 using the approach outlined above. Our sample is exhaustive, since it involves all published work in this field today.

Nr	Authors	Title	Year	Source title	Volume	Issue	Art. No.	Page start	Page end
Results by using the keyword search in Scopus									
1	Jung, M., Park, M., Lee, H. S., & Chi, S	Multimethod Supply chain Simulation Model for High-Rise Building Construction Projects	2018	Journal of Computing in Civil Engineering	32	3	4018007		
2	Jung M.	Agent-Based Simulation Framework for Supply chain Management of Large-Scale Construction Projects	2017	Congress on Computing in Civil Engineering, Proceedings	2017-June			289	296
3	Mostafa S., Chileshe N.	Discrete-event simulation model for offsite manufacturing in Australia	2015	Proceedings of the 31st Annual Association of Researchers in				1043	1052

				Construction Management Conference, ARCOM 2015					
4	Scheffer M., Rahm T., König M.	Simulation-based analysis of surface jobsite logistics in mechanized tunneling	2014	Computing in Civil and Building Engineering - Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering				705	712
5	Vidalakis C., Tookey J.E., Sommerville J.	Demand uncertainty in construction supply chains: A discrete event simulation study	2013	Journal of the Operational Research Society	64	8		1194	1204
6	Taghaddos H., Hermann U., AbouRizk S., Mohamed Y.	Simulation-based scheduling of modular construction using Multi-Agent Resource Allocation	2010	Proceedings - 2nd International Conference on Advances in System Simulation, SIMUL 2010			5601887	115	120
7	Sacks R., Partouche R.	Production flow in the construction of tall buildings	2009	Building a Sustainable Future - Proceedings of the 2009 Construction Research Congress				1019	1028
8	Arbulu R.J., Tommelein I.D., Walsh K.D., Hershauer J.C.	Contributors to lead time in construction supply chains: Case of pipe supports used in power plants	2002	Winter Simulation Conference Proceedings	2			1745	1751
9	Tommelein I.D.	Pull-driven scheduling for pipe-spool installation: Simulation of lean construction technique	1998	Journal of Construction Engineering and Management	124	4		279	288
Results by using the backward and forward search									
10	Arashpour M. , Abbasi B., Reza Hosseini M., Yang R.	Integrated management of on-site, coordination and off-site uncertainty: Theorizing risk analysis within a hybrid project setting	2016	International Journal of Project Management	34	7		1393	1402
11	Poshdarsup M. GPoshdar, M., González, V. A., Raftery, G. M., & Orozco, F. onzalez V.A.	Characterization of process variability in construction	2014	Journal of Construction Engineering and Management	140	11	05014009		
12	Arashpour M., Arashpour M.	Analysis of workflow variability and its impacts on productivity and performance in construction of multistory buildings	2015	Journal of Management in Engineering	31	6	04015006		
13	Hatmoko J.U.D., Scott S.	Simulating the impact of supply chain management practice on the performance of medium-sized building projects	2010	Proceedure Construction Management and Economics	28	1		35	49
14	Love P.E.D., Sing C.-P., Wang X.,	Probability distribution fitting of schedule	2013	Journal of the Operational Research Society	64	8		1231	1247

	Edwards D.J., Odeyinka H.	overruns in construction projects							

Table 1 List of articles find in Scopus and backward and forward search

We extracted from the keyword search 14 papers to conduct the literature review. Table 2 shows the distribution of conference and journal articles over the years. It is used to identify the quality of the input data of our literature review.

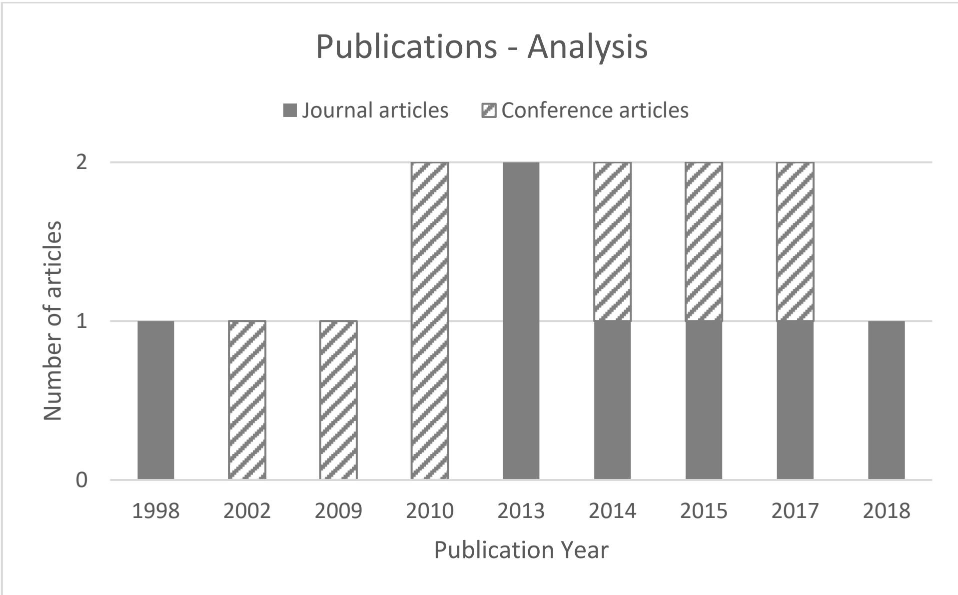


Table 2 Quantitative analysis

2.2 Content analysis of resulting papers

2.2.1 Description of simulation models in construction industry

Related simulation studies in construction supply chain management

Considering construction supply chain management, the lead time represents one of the most important key performance indicators. In Sacks and Partouche (2009) the authors present a parametric discrete event simulation model used to show the impacts of the chosen production strategy in the construction of tall buildings. According to Koskela and Howell (2002), Construction Management has evolved in contract management and the allocation of risks, instead of focusing on production management. Traditionally, a weak design and management of the production system on-site takes place, where each trade team is left to determine its own micro-level strategy (Sacks and Partouche 2009). Moreover, according to Sacks and Harel (2006), especially in the case of unit-price subcontracted work, the trade's strategy is to accumulate buffers of work in order to ensure high productivity on-site by starting work simultaneously in different locations. Therefore, construction participants accumulate consciously and unconsciously buffers of time, work in process (WIP) and materials increasing drastically the construction duration (Sacks and Partouche 2009). The results show that a production strategy of WIP accumulation on-site compared to a WIP reduction strategy contributes to increasingly longer construction durations. In addition, fluctuation in demands can lead to extend the project duration. Vidalakis et al. (2013) present a discrete event simulation study to assess the capacity of material distribution companies to provide a timely and cost efficient service. The main results of the simulation study are that fluctuations in conditions of low levels of demand result in significant lead time increases. Moreover, conditions of higher inventory costs lead to a negative exponential relationship between increasing demand and profits. Considering construction projects for tunnelling an important aspect is that the drilling machine should run continuously. Scheffer et al. (2014) present a discrete event simulation model supporting the planning process in mechanized tunnelling projects. The model simulates the coupling effects of the Tunnel Boring Machine (TBM) advance process, the jobsite layout planning (e.g. the positioning of cranes) and supply chain management in terms of Just-in-Time (JIT) delivery of the needed tunnelling rings. However, the model is just based on a fictive example where the practical validation of the presented approach is missing. Turning back to the lead time analysis for traditional construction projects, Arbulu et al. (2002) show with their models how simulation can be used as a tool to represent a construction supply chain. With the use of simulation, most of the factors that influence the lead time in a supply chain (such as ordering or batch size) can be tested in order to predict the behaviour of a system and thus helping to design a suitable supply chain. Two different scenarios are described in the paper. The first one is a deterministic approach, where results demonstrate a linear relation between batch sizes and supply chain lead time. This consideration can help to adapt the batch sizes improving the overall performance. The second one is a probabilistic approach using a normal distribution. In this second scenario lead times not only increase with an increase in batch size, but also with a decrease in task priority given to the project. Thus, lower task priorities yield increasingly longer lead times. Scope of the simulation is to present a tool for the construction industry to better understand the overall process and how to size the factors to improve the performance of a construction project. They describe the effects of the main design factors such as batching, variability and multitasking. Mostafa and Chileshe (2015) developed by using Arena simulation software a discrete-event simulation model for offsite manufacturing (OSM) supply chains. In Australia, discrete event simulation has been mainly used in specific areas of offsite supply chain, including planning and scheduling of workers. An effective management of information and materials between off-site and on-site is required to avoid any risks along the supply chain. Most of the components are manufactured offsite than transferred to the construction site for installation. In this paper, the simulation is considered as a valuable tool for the evaluation and analysis of the dynamism of a system. In their paper they describe three scenarios: (i) an as-is (design to order), (ii) a what-if I (assembly to order) and (iii) a what-if II scenario (built to order). The two what-if scenarios demonstrated in this study and their simulation results display the significance of the client order information in managing the OSM supply chain. These scenarios showed improvements in terms of house completion time. Some limitations are acknowledged as the study reports on the findings using just limited interviews. Secondly, the model was developed and tested within Australia only. Another simulation study that analyses the lead time was done by Tommelein (1998) focusing on material deliveries. Shee shows a simulation of pull-driven scheduling for pipe spool installations. The aim of the research was to present and compare alternative strategies for sequencing material deliveries using simulation. The Pull technique with progressive feedback from on-site to off-site improves the performances of the project. On the other hand, Push driven approaches, usually supported by a critical path method (CPM), let the activity start as soon as the previous activity is completed. The process in the simulation is

simplified with off-site design and fabrication of pipes and on-site preparation of work areas. Several alternatives for the simulation have been created, considering different criteria. Those are one deterministic (with perfect coordination, no uncertainty and optimal productivity) and three probabilistic models. In the probabilistic models the factor uncertainty and rework is included. The results demonstrate a performance improvement using the Pull approach with a real-time feedback from on-site and off-site to manage the sequencing of works and tasks. According to Tommelein, choosing where, when, and how to pull is an important issue. Many pull links could be created, but each requires money to be implemented and the effects of one link may offset those of another. Arashpoure and Arashpoure (2015) show that the worksite environments of construction projects are often dynamic and subject to a level of variabilities caused by fluctuation of work quantity and reworks. This leads to excessive delays and longer queues of uncompleted jobs which causes a loss of productivity. This paper shows different approaches to analyse variability. The first approach, asthe most popular one, is the critical path method (CPM) with the project evaluation and review technique (PERT). The second one is the discrete event simulation (DES) approach, based on process and operation model. The last approach, again a DES approach, is built on the Workflow Management. The advantage is the possibility to analyse Lean-concepts for delivery systems inside the production stream. Scope of the article is to analyse the effect of variability on the performance of construction projects by a holistic approach considering the trade-level as well as the project-level performance. To analyse the data, a mathematical modelling at the trade level and a DES modelling at the project level was conducted. Findings of the simulations demonstrate how the interval of activities starts are capable to vary the construction performance and productivity. The limitation of this study is that it was only applied to multi-storey buildings.
A key aspect of construction projects is the availability of resources. To manage this aspect Agent-Based Modelling (ABM) is proposed in the literature. Jung (2017) proposes a theoretical framework used to model the main components and flows of large-scale construction projects. Special focus is given to model the interrelationship of project components. According to the author, representing the interrelationship of flows with discrete event simulation (DES) methods is very difficult and therefore an agent-based simulation framework is proposed. The agent-based simulation framework models construction tasks, their needed resources (in terms of space, equipment and crews), the required material (off-site and on-site), and the interconnecting information flow (used to monitor the construction progress and to calculate the appropriate amount of material to be ordered on-site). More in detail, to represent the variability in the performance of material and supply tasks an external risk generator is used. However, the article does not contain any proposed parameters to configure the simulation model. Furthermore, no practical application as well as validation of the proposed framework is shown. In a second publication about resource management, Jung et al. (2018) present a multimethod simulation model composed of Discrete Event Simulation (DES) and Agent-Based Modelling to analyse how sharing limited resources (yard storage space and hoisting equipment) affects construction and material supply processes in high-rise building construction projects. The study deals with a "push-pull" strategy (Jung et al. 2018). The simulated production process follows a push strategy in the way that production/fabrication is based on forecasts of future demand and not according to the construction progress on-site. On the other hand, transportation processes from suppliers follow a Pull strategy, in the way that the delivery is organized according to the real demand on-site. According to the simulation results, the authors suggest that the planning of a construction project should be performed in a holistic way by considering construction and material supply processes as one system (Jung et al. 2018).

However, the article gives just a limited insight into how the scheduling and monitoring process on-site as well as the material release process should be performed in order to implement the push-pull strategy. Like Jung et al., also Taghaddos et.al. (2010) is focusing in their paper the effective allocation of resources. Using multi-agent resource allocation (MARA), the paper describes and analyzes a simulation-based scheduling of modular construction. Modular construction represents a multi-project construction with independent projects. Late delivery of a module may affect the delivery of some other modules. Modular construction processes have many off-site environmental benefits, like higher construction performance, less noise, pollution or waste of material. The best solution for such complex projects is according the authors the "heuristic procedure" for optimization and the "optimum-yielding technique" for scheduling the on-site assembling activities. Nevertheless, the resource management is not considered at all. The novel simulation approach MARA introduces the interdependency of different activities and includes various constrains, like limited workspaces, limited skilled crew or limited equipment. MARA with up-to-date data from a database, allocates trough a protocol the resources to their agents, by maximizing individual welfare, considering also defined priorities for different tasks. This paper presents a hybrid approach for effective allocation of resources among the modules, while delivering the modules on time (and in order) and satisfying the available constraints. This approach allows the system designer to define parameters that affect the welfare (satisfaction) of the agents (modules). For example, late delivery or wasted space in the yard reduces the welfare of the agents and society. Delays in material delivery and its consequences is picked up by Hatmoko et al. (2010) by using a survey and simulation models. Pertmaster Risk ExpertTM software was used to run the simulation models by applying probabilistic risks for supply chain delays to a CPM network of a medium-sized building project of 300 day's duration. The data to configure the simulation model was obtained by means of a survey within the context of a medium-sized building project in the United Kingdom (see Table 1). According to the result of the simulation, delays in material flow had the biggest impact on project performance. More in detail, the project's median delay due to late material deliveries was 25 days (equivalent to 8% of project duration) with a 10% chance of delaying the project by 48 days (equivalent to 16% of project duration) (Hatmoko et al. 2010). Although, the study does not suggest any action contractors should follow to organize their material supply chain in order to avoid late material deliveries to the site.
Poshdarsup et all.(2014) illustrate which kind of distribution can be used by performing a discrete simulation event to analyse the duration of a construction project. If normally the beta probability distribution function PDF is used, the authors explain that this distribution is the best one if you do not consider the coefficient of variation COV. Despite this, the study explains that if the whole project has no variation until a COV of 100%, the beta distribution works linearly. Above 100% this distribution is changing its linear behavior. Between a COV of 100% and 150%, the Burr PDF is the most reliable. The study proofed, that the error by using the Burr distribution with a COV between 100% and 150% will not exceed 13%. In certain cases, the Burr distribution can give you an accurate and flexible representation. Poshdarsup et all. (2014) limited the study to categorize the fitness of the distributions. Additional studies should determine the accuracy of the assumption. To underpin our assumptions of the simulation study, we investigated related studies about the uncertainty of on-site activities.

Related studies investigating the uncertainty of on-site activities

A detailed analysis of on-site activities is required, in order to understand which kind of distributions we should utilize in our simulation model. Love et al. (2013) present an analysis of statistical characteristics of schedule overruns in 276 Australian construction and engineering projects. Based on the presented results, schedule overruns do not vary with project size, type and procurement method. To identify which probability distribution fits best, the construction and engineering data sets were examined using the Kalmogorov-Smirnov and Anderson-Darling tests. The results revealed that the Burr Four Parameter (4P) distribution provided the best fit of all analysed data sets (Love et al. 2013). More in detail, based on different contract sizes, defined in Australian Dollars (AU$), the best distribution fits were identified. Considering a contract size of less than AU$ 1 million and between AU$ 11 million and AU$ 50 million the Wakeby distribution was found to provide the best overall distribution fit (Love et al. 2013). The Log-logistic distribution was found to fit best for contract sizes of AU$ 1 million until AU$ 10 million and the Beta distribution for contract sizes of more than AU$ 51 million (Love et al. 2013). In conclusion, Love et al. (2013) present probability distribution fittings of schedule overruns in a general way without going into the detail of different trades working on construction sites. Arashpour et al. (2016) analyzed different activities of a construction project. Detailed data about off-site and on-site construction activities of two case studies from two large construction companies, were collected and optimal probability distributions were fitted to them. The goodness of fit was proved by using @ Risk probability distribution fitting software and Chi-Square, Anderson-Darling (A-D) and Kolmogorov-Smirnov (K-S) test. In the article, uncertainty in activity durations and workflow was reproduced by fitting optimum probability distributions to the collected data. Interestingly, the rework on rough-in plumbing (on-site) was fitted best to an exponential distribution and the forming and pouring of the foundation concrete (on-site) was modelled by using a triangular distribution (Arashpour et al. 2016). One of the major findings of the article is that an increasing of project work quantities (in terms of man-hours per work packages) results in a linear growth in completion times (Arashpour et al. 2016). Moreover, the study reveals that in so called hybrid construction projects, where a combination of on-site and off-site activities is contemporaneously in progress, the resulting uncertainties should be managed in an integrative manner. Although the paper gives some insight in the uncertainty of on-site activity durations, non-extensive data from practical projects is used and a detailed description and classification of the investigated construction projects (e.g. civil engineering, infrastructure projects and so on) is omitted.

2.2.2 Identification of simulation parameters related to the construction industry

Research work	Parameters for the simulation	Context
Sacks and Partouche 2009	- Triangular distribution (minimum, most common, maximum) - Average Project Resources Duration (months), calculated on 20 simulations - Labor capacity utilization from 89,9% to 90,6%	The paper focuses on modern high-rise office and commercial buildings. Durations of activities for structural walls, columns, slabs and beams were simulated.
Jung et al. 2018	- Discrete probability distribution to model activities of structural work, curtain-wall work, finishing work and MEP work	The simulation model studies large-scale high-rise building construction projects

	- Triangular distribution to model activity times in off-site and on-site material supply processes - 250 simulation runs for each condition	
Vidalakis et.al. 2013	- Number of deliveries: Binominal - Vehicle Initial efficiency: Pearson - Order size: Weibull - Turnaround times: Gamma - Distance travelled: Weibull - 36 Simulation trails were performed incorporating 30 runs each.	The study was carried out in cooperation with two material distribution companies; a builders' merchant (BM) and a construction materials supplier (MS), both based in the outskirts of Glasgow, UK.
Arbulu et. al. 2002	- Task Duration: Normal	This paper deals with a supply chain of pipe supports used in power plants.
Mostafa and Chileshe, 2015	- Task Duration: Triangular	The paper focuses on the supply chain of the Australian housing industry.
Tommelein 1998	- Duration Fabricate: Pertpg - Duration Rework: Pertpg - Duration Transport: Normal	The paper focuses on the materials-management process of pipe spool installation.
Love et.al. 2013	- Construction and engineering projects: Burr (4P) (k=0.19541; α=2.1247E+8; β=5.6456E+8; γ=-5.6456E+8) - Contract range AU$<1m: Wakeby (α=33.005, β=0.29475, γ=0, δ=0, ξ= -5.3672) - Contract range AU$1 - 10m: Log-logistic Three Parameter (α=116.32; β=903.14; γ=-896.46) - Contract range AU$11 - 50m: wakeby (α=242.27; β=9.6408; γ=21.159; δ=-0.29463; ξ= -33.129) - Contract range AU$51 - 100m: Beta (α1=1.0483; α2=0.69063; a=-20.251; b=28.42) - Contract range > AU$100m: Beta (α1=0.53671; α2=0.42258; a=-16.25; b=39.84) - Mean schedule overrun of 11.42% from contract award	A statistical analysis of schedule overruns by using the contract award as reference point in 276 Australian construction and engineering projects is presented in this paper.
Arashpur et al 2016	- Discrete event simulations were run for 1000 times to achieve a confidence level of 99% and standard errors within 0,5% - Exponential distribution for rework on rough-in plumbing (on-site): scale = 1.2 days and threshold = 2.7 days - Triangular distribution for form and pour foundation concrete on-site: optimistic 1.8 days, most likely 3.7 days, pessimistic = 7.6 days	Uncertainty in on-site and off-site activity durations and workflow was studied in this paper. The collected data of two Australian construction companies were fitted to optimum probability distributions. .
Poshdarsup et.al. 2014	- Coefficient of variation < 100%: Beta	The paper deals in a general context of how to model process durations in construction.

	- Coefficient of variation > 100%: Burr	
Hatmoko and Scott 2010	- 20,000 simulation runs where the results converged to 0.01% variation - According to Abou Rizk and Halpin (1992) a beta distribution was used to represent activity durations in construction - Duration of the simulation: 300 days	By using simulation models the article investigates how much supply chain delays impact on project performance of a a typical medium sized building project of 300 days' duration.

Table 3: List of Parameters

3. Theoretical foundations and methods

3.1 General description of procedure to develop a simulation model

According to Buam, a simulation project can be described by using the 10-step procedure. It starts by defining the problem. Then the system parameters and data have to analyzed. Next, it is necessary to create a mathematical model by means of logical rules. After the formulation, a first validation of the model takes place. The fifth step is the programming of a theoretical model and verification. Then, test runs need to be performed. After, a second validation is necessary. Step number seven is the design and execution of the simulation experiments. Later, the simulation results have to be analyzed and last but not least the documentation and presentation of the results. (Buam, 1986)

3.2 Discrete Event Simulation

The discrete event simulation is a time dependent type of simulation. In general, complex system, that show an ordered sequence of determined events, can be modelled. A common practical example, where discrete event simulation is used, is the flow of materials.

Advantages are:

1) Flexible time management, process times and duration
2) Any hypothesis can be considered in a feasibility study
3) Wide range of designing simulations
4) The output can be observed by changing input parameters

Disadvantages are:

1) It is a very time consuming as well as an expensive activity
2) High qualified staff is required
3) In complex systems, all possible interrelations need to be considered

3.3 Flexsim

Flexsim is a discrete event simulation software developed by Flexsim Software Products. 3D models can be simulated, material flow can be animated, various input parameters such as statistical distribution can be assigned to various process steps. Output can be analyzed by using 2D/3D graphics as well as numerical output. Simulation can be run multiple times and in just a little time a long simulation run can be performed.

Application fields:

1) Manufacturing (Lean manufacturing options)
2) Logistics & Distribution (Material transfer systems)
3) Logistics & Distribution (Container port operations)
4) Health care facility design and analysis

3.4 Push systems and Pull systems

Push system:

In a push based system, materials are pushed through the supply channel from the production side to the customer. The actual customer needs are not considered. As a result, higher levels of stock appear. On the other hand, production planning in manufacturing is much more efficient and output oriented.

Pull system:

In a pull based system, materials are pulled through the channel by means of customer demands. Thus, stocks in the supply chain are very low and deliveries can occur just-in-time or just-in-sequence. Production planning is much more complex and time consuming, since we are in a make-to-order environment.

3.5 Gantt diagram to visualize the master schedule

The Gantt diagram is a bar chart named after its inventor, Henry Laurence Gantt. It is mainly known for its largely use in project management. Activities are represented through bars on a time axis. Regarding on the activity and its dependence of previous or successive jobs, they can be pictured in sequence or in parallel. The time axis can be divided in days or in week numbers, depending on the total length of the project. In addition, the visualization of the critical path is possible. Gantt charts are also used for production planning and control.

3.6 Traditional scheduling system as the CPM

The Critical Path Method (CPM) is a project scheduling technique. The critical path of a project, determines the minimum project duration. According to that, it is the longest path or the path with no float. If an activity, which is assigned to the critical path experiences delays, the hole project is going to run late. On the other hand, if an activity finishes earlier than planned, the project duration is going to be shortened. CPM uses network diagrams with arrows, to graphically show activities. In order to create such a network diagram, each activity needs an estimated duration and relationship to other activities.

3.7 Earned Value Analysis (EVA) to monitor a traditional construction project

The Earned Value Analysis (EVA) is a project management method for measuring project performance. The EVA technique takes into consideration the triangle measurements of project management: scope, time and costs. EVA enables the Project Manager to provide accurate forecasts.

Common, Earned Value Analysis, indexes:

- PV (Planned Value)
- EV (Earned Value)

- AC (Actual Costs)
- SPI (Schedule Performance Index)
- CPI (Cost Performance Index)

In addition, it can be also used as a way to communicate through project stakeholders and for project reporting. In order to predict future conditions, such as under or over budget as precise as possible, it is necessary to repeat the analysis in regular time intervals through the project lifecycle.

3.8 Last Planner System

The Last Planner System, is a method designed for lean construction project management. It applies lean production principles of a traditional manufacturing environment, to construction. The aim is to improve the reliability of planning processes in construction, through cooperative and look-ahead planning. One way to achieve this, is to empower and encourage crews who are on-site, to plan and schedule tasks. Thus, decision making can also be decentralized. The traditional Master Schedule steps in the background and serves more as an overall view, that shows major project phases. Instead, tasks are assigned through weekly work planning. The Last Planner System, is a Pull-oriented process.

4. Conceptual part of the work

4.1 Hypothesis and research question

A decentralized and pull based planning and monitoring approach to deliver ETO components on-site, reduces the average level of buffers on-site.
By means of a real-time planning and measuring of the construction process on-site (in a weekly frequency) we state that it is possible to reduce the average content of buffers on-site more than the conventional Pull-system, where material is ordered based on a minimum stock level or the traditional Push System, where material is delivered by means of a static Master Production Schedule.

4.2 Context Construction Supply chain Management

Supply chain Management is commonly defined as the management of upstream and downstream value-added flows of: information, materials and final goods starting from suppliers amid the company and resellers, to the final customer. In construction, the supply chains are generally Make-to-Order configured. Hence, all goods are converged to the site where the assembling of the incoming material takes place.
According to the specific type of material that is assembled, different supply chain configurations with different lead times have to be considered in a construction environment. For instance: consumable materials such as bolts are Make-to-Stock configured, doors and windows Assemble-to-Order, prefabricated materials Make-to-Order and finally high-end design facades are Engineer-to-Order arranged.

In this study project, it is assumed that construction supply chains are instable and inefficient, where Supply chain Management practices and methods from manufacturing cannot be directly applied.
During this study we applied Push and Pull principles from manufacturing and adapted them in order to fit in a construction context, with the aim of improving the supply chain by reducing inventories on site. In this context we defined real-time as weekly scheduling and monitoring. Of course, compared with the industrial environment real-time means a measurement frequency of steering information in the range of seconds or minutes. This because a conventional product in the manufacturing environment would have a "Takt Time" of e.g. 3 minutes. However, in the construction industry the erection of a building would have a delivery time of e.g. 2 years. Therefore, a weekly measurement can be interpreted as real-time in this context.

4.3 Description of the Push Model

In the Push model the production plan at the supplier's site is centralized following a Master Production Schedule. In this context an Engineer-to-Order (ETO) production plan has to be considered, since all components are customized for each construction site. Each construction site has its own schedule, which was created at the very beginning by the Project Manager. Such a schedule can be created based on the Project Managers experience, involving all parties taking part to a construction project. The production schedules of each construction site are then consolidated into one Master Production

Schedule. The Master Production Schedule is needed to plan fabrication and engineering activities at the supplier's site, as well as for Material Requirement Planning (MRP) for the purchasing department. The MRP is usually performed by the supplier's ERP system, where the components have their Bill of Material, which unleash a demand of the raw materials. The delivery of the fabricated components is then also organized through the Master Production Schedule. The produced ETO components are stored in a buffer area and later delivered to the construction site. In this project we defined these components as so called, pitches. A "Pitch" defines the amount of construction Areas (e.g., 2 rooms) which can be completed by a specific Crew (composed of a minimum number of workforce e.g. 4 workers) in a specific time Interval (e.g., 1 day or 1 week) (Dallasega et al. 2016). As such, a Pitch defines in our case the material needed for one working week on-site. In other words, the Pitch defines the amount of material needed for an uninterrupted installation process on-site in a time interval of one week.
The Master Production Schedule is considered static, where deviations of the construction sites are not considered.

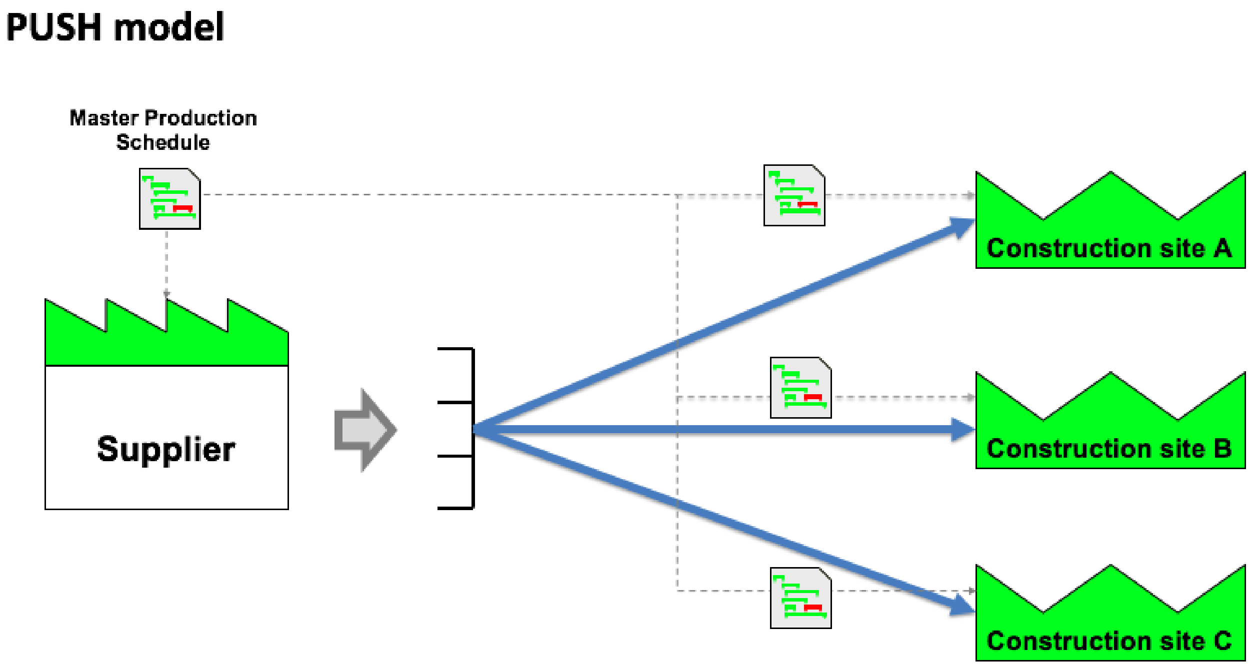


Figure 1: PUSH model

4.4 Description of Pull Model

In our Pull model the production schedules at the constructions site are created using the same procedure as in the Push model, with the difference that they are periodically updated taking into consideration all deviations on the construction site and therefore providing an active feedback loop to the supplier. Thus, the Master Production Schedule at the supplier is not static but dynamic. Deviations from the production plan are registered as soon as they appear and the Master Production Schedule is updated in real time. Such an information exchange between all parties involved in a construction project, is only possible if emerging trends such as Cyber-Physical Systems, the Internet of Things, sensor-networks and RFID technologies are used. The ultimate goal is to reduce the stock of ETO components at the construction site on what is actually needed and thus eliminating non value adding activities like searching and waiting. Furthermore, money can be saved by reducing the storage area and the risk that components are damaged or even stolen will be reduced.

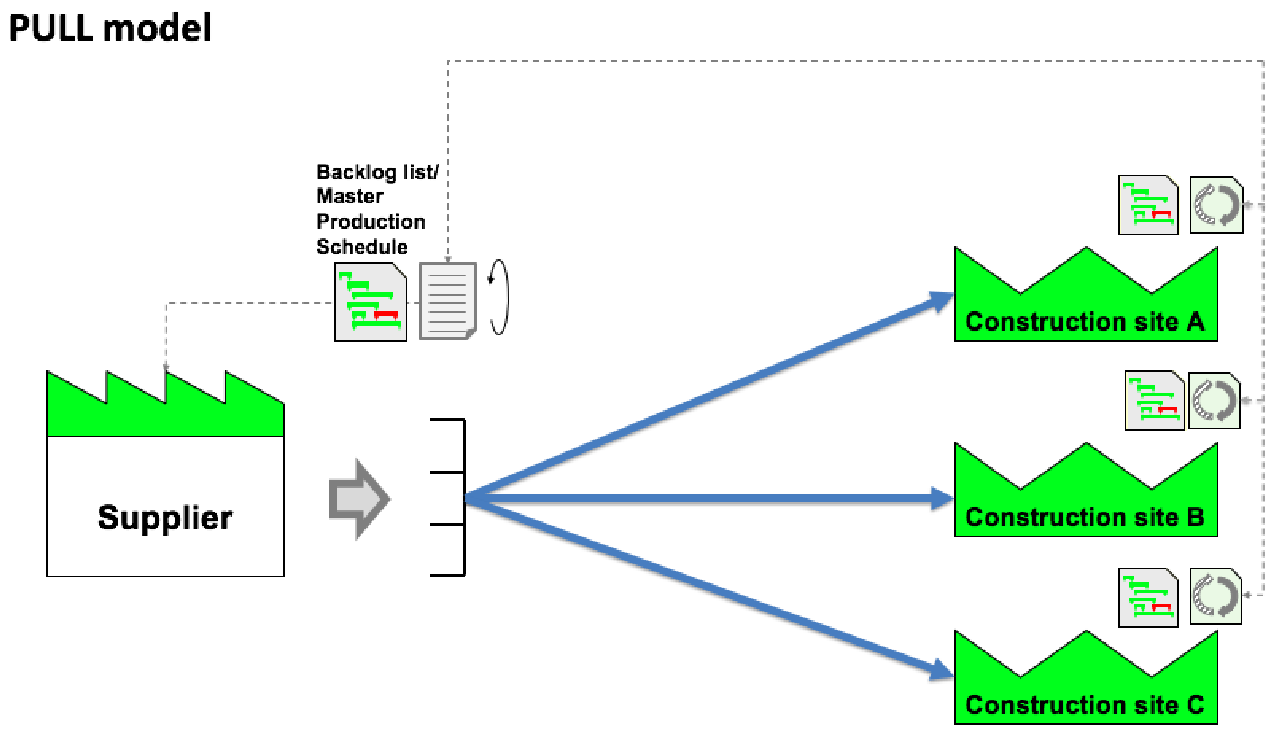


Figure 2: PULL model

4.5 Definition of KPIs

In our study we defined a total of three KPIs for a better comparison of the simulation models, as well as for an economic analysis. The KPIs are:

- **Processing workload**
- **Average content**
- **Average stay-time**

The processing workload refers to the average utilization of the construction site. Processing time is contrasted to the idle time.
The average content is the amount of pitches in the storage area next to the construction site.
Finally yet importantly, the average stay-time refers to the average time, that a pitch is stored in the storage area, until the construction site makes the call-off.
This three KPIs are computed in all simulation model and then confronted to make a statement on how and to what extend the different planning approaches have an impact on the KPIs itself.

5 Simulation model based on a real case study

5.1 Description of the case study F&R

This study project was initiated in collaboration with the company Frener & Reifer GmbH (F&R). F&R is a medium sized company located in Brixen in the North of Italy. It is European leader in the delivery of high-class design facades.
The delivery of so called Pitches from the supplier (F&R) to the sites, should be compared by using a traditional Push approach following a Master Production Schedule and a Real-Time Pull approach where the Master Production Schedule is updated according the real demands on the construction sites.
The Master Production Schedules is elaborated during the process planning workshops by the responsible of the Engineering department, the installation supervisor and the Project Manger. The Schedule contains all production activities, milestones and deadlines that were agreed previously with the customers.
The project planning, the production scheduling as well as the monitoring of performance is done and supported by the company's ERP system.

5.2 Figures description of the simulation Model

In the following table a general description, of the figures used in our Flexsim simulation models, is listed. It is valid for the Push model, as well as for the Pull model.

Figure	Description
	The source is used to create the flow items that travel through a model. Each source creates one class of flow item and can then assign properties such as item type or color to the flow items it creates. Models should have at least one source in them. Sources can create flow items per an inter-arrival rate, per a scheduled arrival list, or simply from a defined arrival sequence. In our simulation model it represents the output of the manufacturer.
	The sink is used to destroy flow items that are finished in the model. Once a flow item has traveled into a sink, it cannot be recovered. Any data collection involving flow items, that are about to leave the model should be done either before the flow item enters the sink or in the sink's on entry trigger.

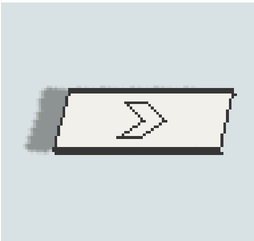
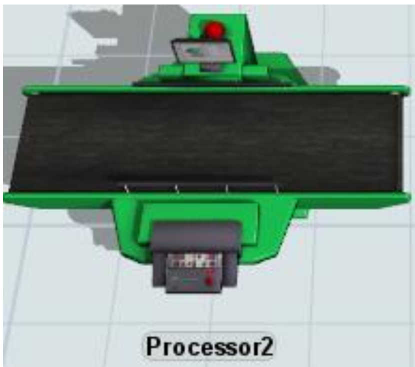
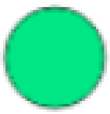
	The queue is used to store flow items, when a downstream object cannot accept them yet. By default, the queue works in a first-in-first-out manner, meaning that when the downstream object becomes available, the flow item that has been waiting for that object the longest will leave the queue first. The queue has options for accumulating flow items into a batch before releasing them. In our simulation model it represents the buffer on the construction site as well as the issuing area of the manufacturer
	The straight conveyor can simulate conveyor belts or roller conveyors. In our simulation model it represents the path from the issuing area of the manufacturer to the storage area of the construction site.
	A processor is used to simulate the processing of flow items in a simulation model. The process itself is simply modeled as a forced time delay. The total time is split between: a process time and a set-up time. The processor is able to process more than one flow item at a time. Processors may call for operators during their processing times, as well as for set-up times. When a processor breaks down, all of the flow items that it is processing will be delayed. In our simulation model it represents the construction site.
	In Flexsim the token is the most basic component for Process Flow. Each Token can be seen as a bundle of data that is moving thought the Process Flow. It can contain: ID number, Name and Label. In our simulation model we use the Token for representing the Pitch.
Source: www.flexsim.com	

Table 4: Flexsim figures

5.3 Model description Push

In the following picture the Flexsim Push simulation model is shown.

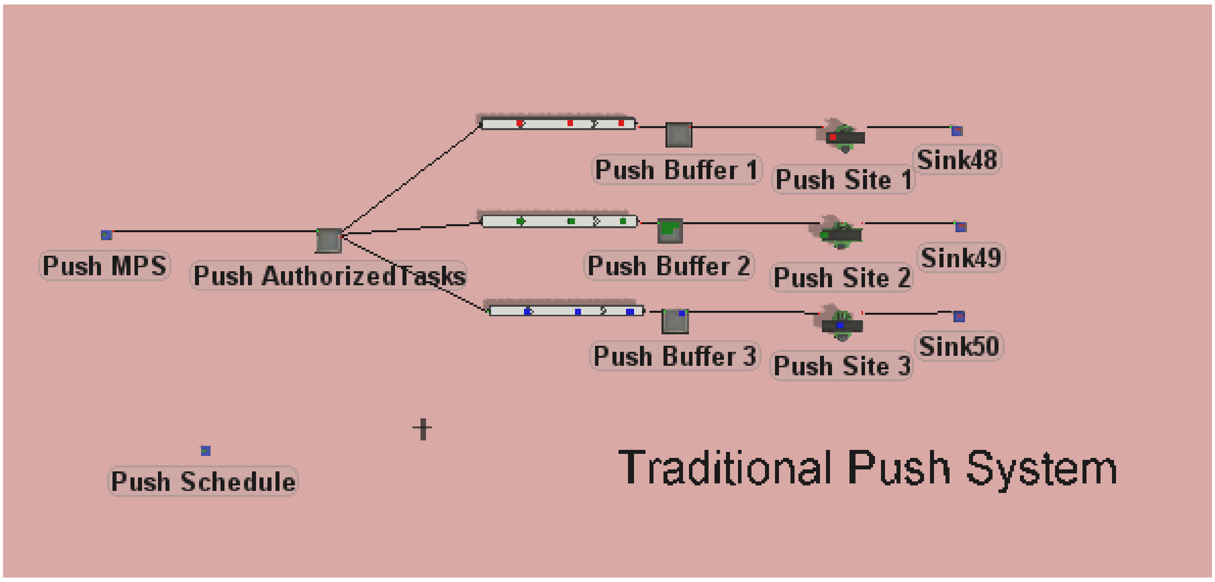


Figure 3: PUSH Flexsim model

This model follows the classical Push principle, where the manufacturer has a Master Production Schedule, which is followed. The Pitches, as soon as they are finished, they will be delivered to the construction site. The construction site, calls the pitches off, on-demand. In the meantime, the pitches are stored in the buffer on the construction site.
In the simulation model the Master Production Schedule is defined in the sink called, Push MPS. The sink has an arrival style set on arrival schedule and a total number of 369 arrivals. The amount of arrivals is split in 3 different item types, which in the context act as Pitches that will be delivered to the corresponding construction site. Each Pitch has its destination defined in the Master Production Schedule.
After the sink there is a Queue called Push Authorized Tasks, this Queue acts as a goods out storage area, at the manufacturers site. As soon as the Pitch is authorized to leave the manufacturers site, it travels to the corresponding construction site.
Each of the three construction sites has its own storage area. In the model again a Queue is used.
The construction site is represented through a processor. The process time of the construction site is exponentially distributed. The distribution has following parameter: location 4, scale 1, stream 0. This means that, a Pitch has a minimum duration of 4 and an average delay of 1 day, which results in an average duration of 5 days.
This is valid for all three sites. With this parameter the deviations and delays that can occur on a construction site, are considered.

5.4 Model description Pull

The Pull simulation model considers 2 approaches: 1) the traditional Pull approach, where Pitches are sent to the construction site according to a minimum buffer level, which in our simulation model is 3 pitches 2)the Pull principle was improved in a way that the delays of

Pitches are measured directly on the construction site and not indirectly by the filling up of the buffers.

In the first figure the model of the traditional Pull system is visualized.

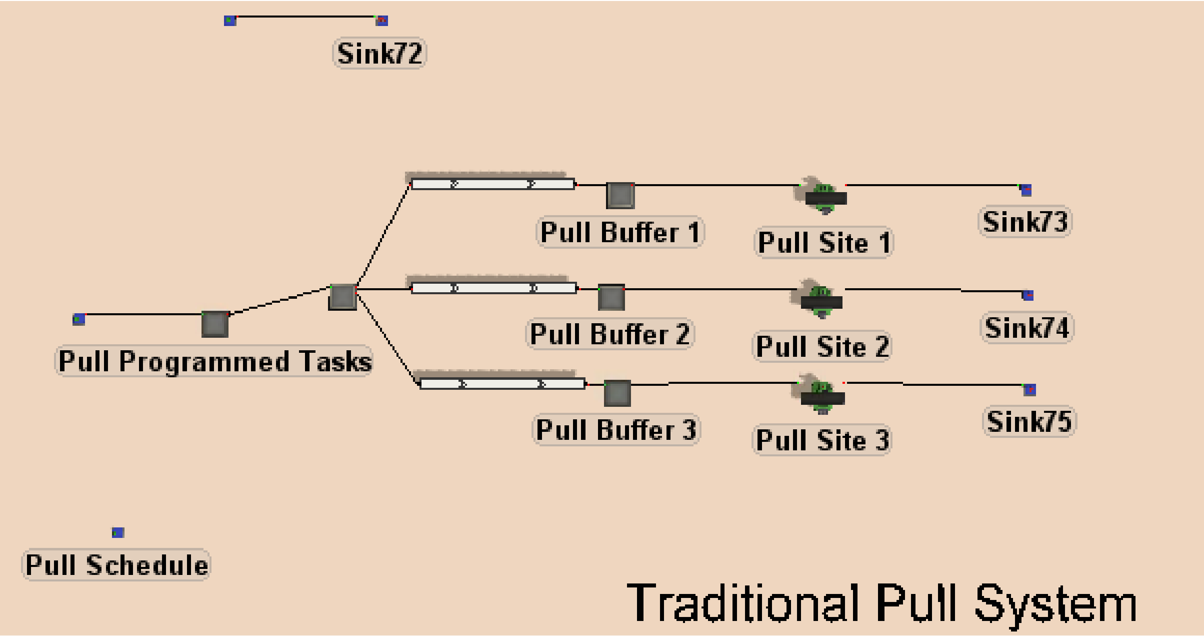


Figure 4: PULL Flexsim model (traditional)

In contrast to the Push simulation model, in both Pull models there is one more Queue that is needed for the Programmed Tasks. It is located in between the Sink that contains the Master Production Schedule and the Queue for the Authorized Tasks. This is needed for prioritizing the Pitches and making sure that only those Pitches that are needed on the site are actually delivered on the site. The aim is obviously to have lower stocks on the site. In the traditional Pull System material is ordered on-site, through minimum stock levels.

In the next figure the Real-Time Pull model is pictured. In this model all deviations on site should be considered and result in an update on the Master Production Schedule, due to shifts in prioritization of the Pitches. In order to implement this, there is a communication exchange needed between the sites and the manufacturers. This communication exchange has a direct impact on the Master Production Schedule, since so the Manufacturer is always updated on what is happening on site. For this an algorithm was developed and transcribed in a code, in order to implement it in the simulation model. Thus, the planning and monitoring process is decentralized and real-time updated. The update occurs in a weekly interval, since the average duration of a Frener & Reifer construction project is roundabout 2 years.

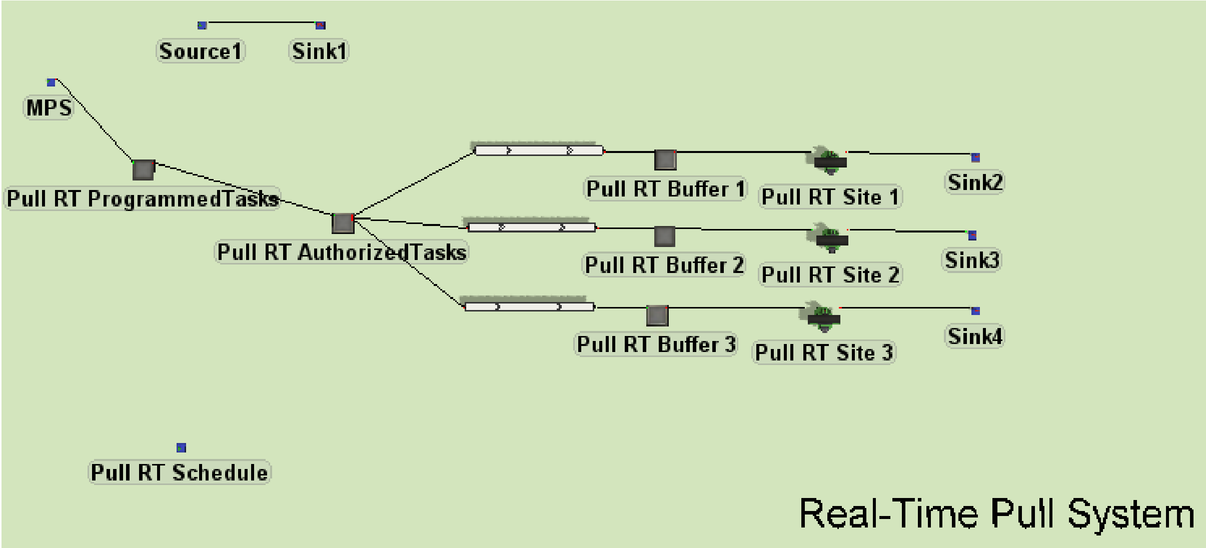


Figure 5: PULL Flexsim model (real-time)

5.5 Configuration of dashboard

The dashboard in Flexsim allows the user to view graphs, charts and statistics for the model as it runs. This is particularly useful for comparing objects side by side. The charts can be parametrized and customized in a way to show specific data and for an aimed analysis.

Regarding the dashboard configuration of the simulation model, the focus was on the KPIs that were defined under section 4.5. To recap, the KPIs were:

- **Processing workload**
- **Average content**
- **Average stay-time**

For the processing workload utilization of the construction sites, a pie chart was used. It Shows the percentage of the processing time vs. the idle time.
The average content which is located on a storage area next to the construction site, called buffer, is displayed as number of pitches in the buffer.
The average stay-time, refers to average time a pitch is stored in the buffer, till the actual call-off from the construction site. For this analysis we used a bar chart to display the average time.

6 Description of results and validation

6.1 Simulation scenario

The number of runs in the simulation scenario is 100. This is done by using the experimenter in Flexsim. Having such a high number of runs allows us to give better statements on the actual results. The installation on site is exponentially distributed with a minimum duration of Pitches of 4 days and an average delay of one day. Thus, the more runs the better the outcome. The average length of a medium sized project at Frener & Reifer, is roundabout 2 years. Therefore, in the simulation we stipulated a duration of 116 weeks and we established that one Pitch equals one week. The resulting planning cycle, which is done weekly for rolling three weeks, is shown in the image above. The first three weeks are to be considered a frozen period, deterministic talking 15 days.

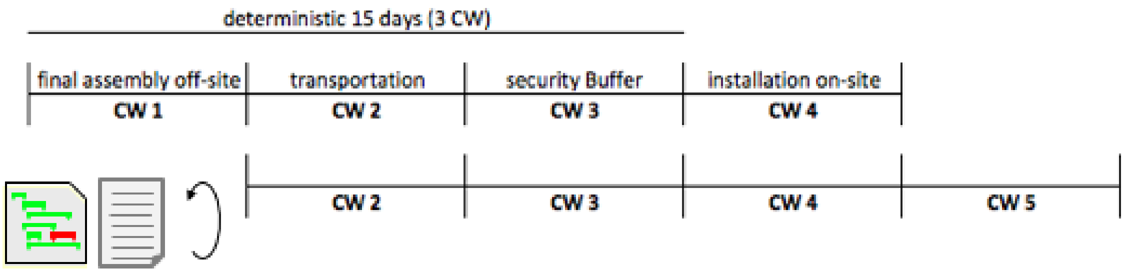


Figure 6: Planning cycle

6.2 Comparison between Push and Pull based on KPIs

In the following image, the dashboard configuration of the Push model is shown.

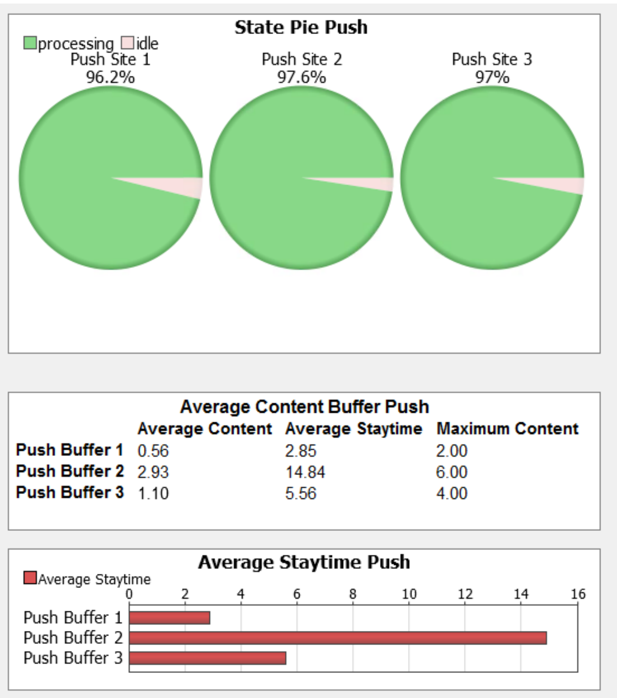
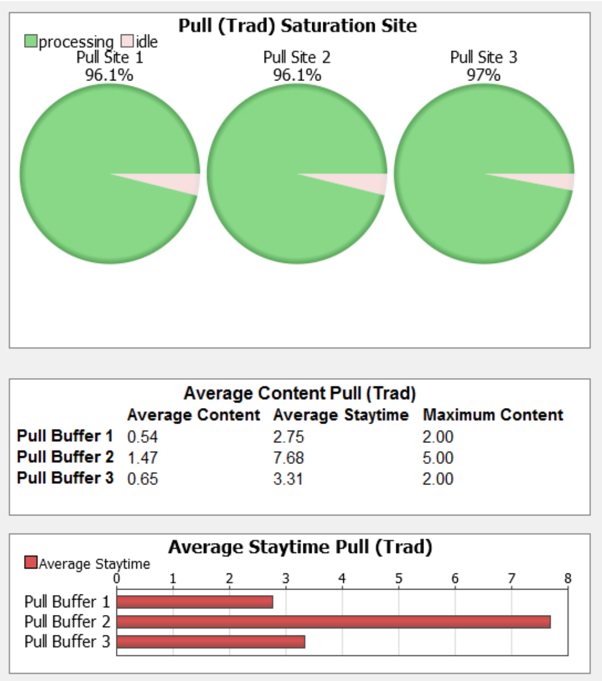


Figure 7: Dashboard results 1

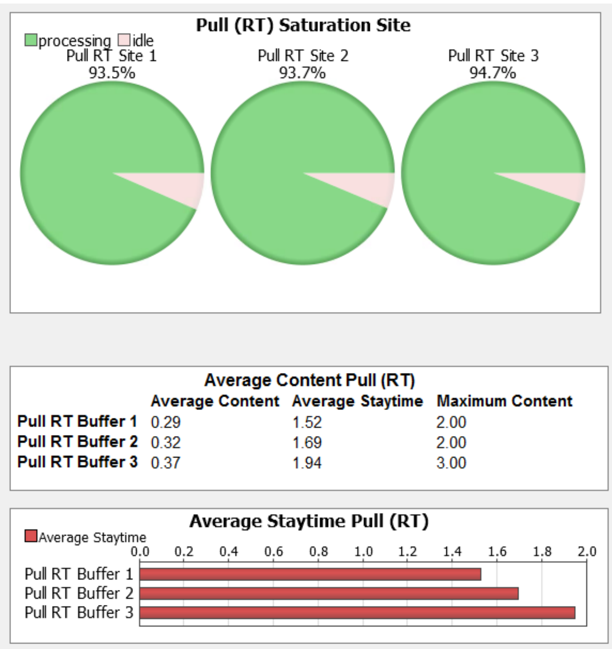
In the next image, the dashboard configuration of the traditional Pull model is shown.



	Average Content	Average Staytime	Maximum Content
Pull Buffer 1	0.54	2.75	2.00
Pull Buffer 2	1.47	7.68	5.00
Pull Buffer 3	0.65	3.31	2.00

Figure 8: Dashboard results 2

Last the dashboard of the real-time Pull model is visualized.



	Average Content	Average Staytime	Maximum Content
Pull RT Buffer 1	0.29	1.52	2.00
Pull RT Buffer 2	0.32	1.69	2.00
Pull RT Buffer 3	0.37	1.94	3.00

Figure 9: Dashboard results 3

If all three evaluations are confronted in one table, following schedule results:

	Push	Pull (traditional)	Pull (real-time)	percentual diff. Pull RT vs. Push
Construction Site workload	96,9%	96,4%	94,0%	-2,9%
Avereage content buffer (picthes)	1,53	0,89	0,29	81,0%
Average stay-time buffer (days)	7,75	4,58	1,72	77,8%

Table 5: Summary of results

Here the average of the three construction sites workload and the average of the three buffers content or stay-time were calculated.
If the best and worst KPI outcome were compared, following can be said:
The construction site workload of the Push model is 2,9% higher than the one of the Pull (real-time) model.
The average content of the Pull (real-time) is 81% less, than the one of the Push model.
Last but not least the average stay-time of the Pull (real-time) model is 77,8% smaller than the average stay-time of the Push model.
From this numbers it can be concluded, that the logic (Push vs. Pull) with which the Pitches are delivered to the construction site has a very little impact on the actual utilization rate of the construction site. In this simulation model it is slightly with Push logic. This could be due to the fact, that in a Push delivery, there are always Pitches available. Whereas in a Pull model last minute delivery bottlenecks can occur, because of the low content in the construction buffers.
The biggest payoff is the reduction of the content (amount of Pitches) in the construction buffers, as well as the decrease of the Pitches stay-time in the buffers, in both cases by almost 80%. This is a great result and means that storage area in a Pull (real-time) principle can be designed by a significant coefficient smaller, than in a Push model. Furthermore, lower stocks next to the construction site means: lower risks that Pitches are damaged or stolen while they are stored and of course lower capital commitment of the stored goods. Also the storage area, which often is built on a stretch of land next to the site, can be designed considerably smaller. Thus, money can be saved.

7 Summary

To sum up we can say that our hypothesis of lower stocks at the buffers on the construction sites was confirmed by comparing and studying the traditional Push delivery system with a conventional Pull-system, that works with minimum stock levels and ultimately with a nearly real-time Pull approach. This planning and monitoring approaches are mostly known to find practice in the processing industry, where goods that are produced are programmed in ERP and/or MES software at a specific "Takt-Time". In this cases the update interval in order to understand the progress of manufacturing orders is often in a range of seconds or minutes according to the output. So in our case when we talk about a real-time planning approach in construction industry this time frame has to be extended to a weekly interval because construction projects have a timeline of almost 2 years. According to the literature review, nowadays, a lot of research is done about simulations, also in the field of construction projects. Many papers handle lead time reductions based on different approaches. Also resources management is taken in consideration to improve the efficiency of projects. In our study, the focus is to improve the on-site delivery management . The literature review is helping us, providing parameter we could insert in the simulation to make it as realistic as possible. Those parameters are related for example, of which statistical distributions could be fit the best for certain activities in our simulations.
We implemented all functions and parameters in our simulation models. A total of three simulations model were designed: a traditional Push model, a traditional Pull model and a Pull real-time model. Once the models were set, various simulations runs were performed to achieve reliable results. The desired outcomes were: the actual utilization rate of the construction sites, the average stay-time of the Pitches in the Buffer and finally the amount of Pitches in the Buffer. While the utilization rate remains pretty much constant in all three simulation models, we were able to reduce the stay-time and the amount of the Pitches in the storage area next to construction site significantly in the real-time planning approach. If we compare the Push model with the real-time Pull model, the amount of Pitches and the stay-time of the Pitches in the construction site buffers were reduced by almost 80% in the real-time model. The storage area on sites can be designed smaller, which leads to further cost saving. Lower amount of stocks means more visibility and less capital commitment. Moreover, less buffer levels on-site can reduce the amount of non-value-added labor such as searching and moving of material. Additionally the risk that material on the storage area could be damaged or even stolen can be significantly reduced.

References:

Arashpour, M., Wakefield, R., Lee, E. W. M., Chan, R., & Hosseini, M. R. (2016). Analysis of interacting uncertainties in on-site and off-site activities: Implications for hybrid construction. International Journal of Project Management, 34(7), 1393-1402.

Arashpour, M., & Arashpour, M. (2015). Analysis of workflow variability and its impacts on productivity and performance in construction of multistory buildings. Journal of Management in Engineering, 31(6), 04015006.

Arbulu, R. J., Tommelein, I. D., Walsh, K. D., & Hershauer, J. C. (2002, December). CEPM 3: contributors to lead time in construction supply chains: case of pipe supports used in power plants. In Proceedings of the 34th conference on Winter simulation: exploring new frontiers (pp. 1745-1751). Winter Simulation Conference.

Hatmoko, J. U. D., & Scott, S. (2010). Simulating the impact of supply chain management practice on the performance of medium-sized building projects. Construction Management and Economics, 28(1), 35-49.

Jung, M. Agent-Based Simulation Framework for Supply chain Management of Large-Scale Construction Projects. In Computing in Civil Engineering 2017 (pp. 289-296).

Jung, M., Park, M., Lee, H. S., & Chi, S. (2018). Multimethod Supply chain Simulation Model for High-Rise Building Construction Projects. Journal of Computing in Civil Engineering, 32(3), 04018007.

Love, P. E., Sing, C. P., Wang, X., Edwards, D. J., & Odeyinka, H. (2013). Probability distribution fitting of schedule overruns in construction projects. Journal of the Operational Research Society, 64(8), 1231-1247.

Mostafa, S., & Chileshe, N. (2015). Discrete-event simulation model for offsite manufacturing in Australia.

Poshdar, M., González, V. A., Raftery, G. M., & Orozco, F. (2014). Characterization of process variability in construction. Journal of Construction Engineering and Management, 140(11), 05014009.

Sacks, R., & Partouche, R. (2009). Production Flow in the Construction of Tall Buildings. In Construction Research Congress 2009: Building a Sustainable Future (pp. 1019-1028).

Scheffer, M., Rahm, T., & König, M. (2014). Simulation-based analysis of surface jobsite logistics in mechanized tunneling. In Computing in Civil and Building Engineering (2014) (pp. 705-712).

Taghaddos, H., Hermann, U., AbouRizk, S., & Mohamed, Y. (2010, August). Simulation-based scheduling of modular construction using multi-agent resource allocation. In Advances in System Simulation (SIMUL), 2010 Second International Conference on (pp. 115-120). IEEE.

Tommelein, I. D. (1998). Pull-driven scheduling for pipe-spool installation: Simulation of lean construction technique. Journal of construction engineering and management, 124(4), 279-288.

Vidalakis, C., Tookey, J. E., & Sommerville, J. (2013). Demand uncertainty in construction supply chains: a discrete event simulation study. Journal of the Operational Research Society, 64(8), 1194-1204.