The Value of Lean Construction

A model of performance measurement for lean building projects

Wim van den Bouwhuijsen
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This study has been made possible by a contribution of the UCB foundation (Stichting Universitair Centrum voor Bouwproductie).

Cover design: part of the poster *Lean by SME builders* by Wim van den Bouwhuijsen, presented at the *Speerpunt Bouw* symposium in Delft in 2008.

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1. Introduction

1.1 General

Despite the new management methods in the construction industry, not enough progress has been made in terms of efficiency. Even after approximately 15 years, there has been minimal use of lean construction methods to improve efficiency. According to Stevens (Matt Stevens, 2013), the main reason is that construction companies, because they make little profit and are exposed to considerable risks, do not invest as long as there is no evidence of the benefits. He also believes that there is no single measure available to construction companies to compare their efficiency, so that they have no incentive to switch to lean construction methods.

The second reason concerns production processes, where measuring results is again an important factor. Our research is based on the method used by Womack et al. to determine the differences in production between assembly plants in their study of the car industry (Womack et al., 2007). This entire study has been conducted and written from the perspective of the general contractor.

Figure 1-1 illustrates the lean production process of the general contractor.

Figure 1-1 Lean Project Delivery System (Ballard and Tommelein, 2012).
The *production control* and *work structuring* bars in figure 1-1 represent production management during the project. Ballard and Howell (Ballard & Howell, 2003) highlight a number of differences between lean and non-lean project delivery (see table 1-1).

### Table 1-1 Lean versus non-lean project delivery (Ballard & Howell, 2003).

<table>
<thead>
<tr>
<th>LEAN</th>
<th>NON-LEAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus is on the production system.</td>
<td>Focus is on transactions and contracts.</td>
</tr>
<tr>
<td>Transformation, flow and value goals.</td>
<td>Transformation goal.</td>
</tr>
<tr>
<td>Downstream players are involved in upstream decisions.</td>
<td>Decisions are made sequentially by specialists and ‘thrown over the wall’.</td>
</tr>
<tr>
<td>Product and process are designed together.</td>
<td>Product design is completed, then process design begins.</td>
</tr>
<tr>
<td>All product life cycle stages are considered in design.</td>
<td>Not all product life cycle stages are considered in design.</td>
</tr>
<tr>
<td>Activities are performed at the last responsible moment.</td>
<td>Activities are performed as soon as possible.</td>
</tr>
<tr>
<td>Systematic efforts are made to reduce supply chain lead times.</td>
<td>Separate organizations link together through the market and take what the market offers.</td>
</tr>
<tr>
<td>Learning is incorporated into project, firm and supply chain management.</td>
<td>Learning occurs sporadically.</td>
</tr>
<tr>
<td>Stakeholder interests are aligned.</td>
<td>Stakeholder interests are not aligned.</td>
</tr>
<tr>
<td>Buffers are sized and located to perform their function of absorbing system variability.</td>
<td>Buffers are sized and located for local optimization.</td>
</tr>
</tbody>
</table>
Positive Iteration in Design, and Application of Lean Rules and Tools to Precast Concrete Fabrication.

This study follows the same structure as Womack’s study, *The Machine that Changed the World* (TMTCTW) (Womack et al., 2007). The objective, indicators and benchmarking used in Womack’s study can be used for the construction industry too.
1.2 Central research question

The formulated objective leads to the following central research questions:
• Can the method applied by Womack et al. for the automotive industry also be used for building projects?
• What indicators can we use to measure the performance of building projects?

1.3 Methodology

We have taken the study conducted by Womack et al. as the basis for our own research. We explain the elements used in that study along with the associated indicators, and we translate them for the construction industry. ENCORD’s Lean Construction Working Group held three preparatory meetings during which the purpose of the study was explained, and at the third meeting an expert panel was set up comprising members of the Group. The expert panel reviewed the indicators mentioned for buildings in table 2-3 and added new ones over the course of four web meetings and a final closing meeting.

We will first discuss the study by Womack et al. and then translate the indicators from the automotive industry to the construction sector. The second part starts with a general section on expert panels, followed by a look at the activities carried out by expert panels. The result is a list of indicators for the process of a building project (see table 4-1). The diagram below illustrates the stages of the study by the expert panel:

```
Add construction industry indicators to the Womack et al. overview

Discuss the indicators in four web meetings, one element per web meeting

Discuss each element in each group (4 times)

Explanation and discussion of each element together

Joint final discussion of all elements
```

Figure 1-2 The stages of the study.
2. Womack’s study in The Machine that Changed the World (TMTCTW) (Womack et al., 2007)

2.1 Introduction

According to the authors, the crux of Womack’s study is that “it tells the story of lean production, Toyota’s secret weapon in the global car wars that is revolutionizing the world industry”. Comparisons are made between different assembly plants across the globe. These comparisons present the productivity and the quality of the different plants. For the construction industry, it is also interesting to know what the productivity and delivered quality is like for different building projects. The situation the automotive industry was facing at that time is also very similar to the current situation in the construction industry. Table 2-1 on the next page presents the key similarities with the construction industry.
The opportunities in the industry at the time. The current opportunities in construction.

The energy issue at the time and in the future. The built-up environment is the largest energy consumer.

Little change in production methods in North America and Europe. Little change in actual production process.

The rapid rise of the Japanese car industry. Cheap labor from Eastern Europe and other low wage countries.

Erecting trade barriers instead of changing production methods. Lots of legislation instead listening to the industry.

The fear of an economic downturn. The fear of an economic downturn, just as we are climbing out of recession.

The insight that things cannot continue as they are. The insight that things cannot continue as they are. Construction is not recovering yet and it will probably be quite some time before it does.

Essential collaboration between car manufacturers worldwide and governments. Understanding and collaboration between the construction industry and governments.
In short, production methods were no longer up to date and, despite the car industry’s rosy future, there were major concerns about the continuity of production, a situation which is not dissimilar to the one in which the construction industry currently finds itself. Based on a belief in the principles of lean production for the construction industry (aka lean construction), the division into elements (i.e. collaboration across the stages of the construction process) and the following statement from the authors: “in this process we’ve become convinced that the principles of lean production can be applied equally in every industry across the globe and that the conversion to lean production will have a profound effect on human society, it will truly change the world”, we were inspired to conduct further research into the performance indicators for lean construction.

2.2 How does the method used by Womack et al. work?

This method utilizes Key Performance Indicators (KPI’s). These KPIs are compared in different ways, e.g. by region, country, continent, brand, etc. This leads to a number of findings identifying the best and poorest performance. The best results are then reviewed to determine why production/assembly is so much more efficient. Toyota’s productivity or that of affiliated car assembly plants often scores much better than other car assembly plants. These companies have a better way of managing the production process. At Toyota, this is called the Toyota Production System (TPS). In the Womack et al. (Womack et al., 2007) study, J. Krafcik dubbed this management method lean production.

2.3 The structure of Womack’s research

TMTCTW uses a framework for the organization of the car industry and divides the time spent from designing the car to its delivery into separate elements called the elements of lean production (see figure 2-1).

Running the factory. The authors were first drawn to this because this element is the most understandable to most people, assembly is the same everywhere and because Japanese car manufacturers wanted to increase production and so were busy building assembly plants in North America. The measurement parameters used are productivity, quality, errors, etc. (see table 2-3, column CAR).

Designing the car is the next element. The most important factor for us is the approach to design; the design is made as per the customer’s requirements in collaboration with the supplier and the assembly plant. For the parameters used, see table 2-3, column CAR.
Coordinating the supply chain. Supply chain management can be viewed as demanding innovation that is built on prior changes such as TQM and Just in Time (JIT). The massive task of getting all the different parts in the right sequence, in the right place at the right time is probably the biggest challenge facing the car industry. Henry Ford solved this problem by producing everything in his own company. Alfred Sloan of General Motors did the same, but set up decentralized business units producing parts to be less dependent on suppliers. Largely composite parts are provided by suppliers, who also assemble some of the parts. This stage covers the bulk of the production process (see table 2-3, column CAR).

Dealing with the customer. The customer is the most important factor in lean philosophy. Due to the nature of the car, which is traded in repeatedly, the customer approach differs per region and is unlike that of other capital goods, which only need replacing once or twice. This is the end of the production process, but the start of the lean production process. The associated parameters used are shown in table 2-3, column CAR.
2.4 Matching the structure of Womack’s study to the construction industry

A building site can be seen as a place where parts are assembled and, like an assembly plant, where most of the activities to be coordinated to create the final product are carried out. In theory, every building project is the same; it starts with a foundation and ends with a roof. When a construction firm wants to work abroad, it generally gets to do so on a project-by-project basis. “Projects are temporary production systems” (Ballard et al., 2007). The difference is the location of the activities; in the case of car assembly, work is done in the same place in a factory, e.g. each time the same parts or composite parts are built or dismantled. This fully completes the assembly and the product is ready for the next step. This, it should be noted, presents a major challenge to the construction industry.

In construction, it is very important to adjust the design to the sequence, method, materials and tools is in order to ensure that you end up with a sound process.

The construction industry is also increasingly using supply chain management and working with suppliers/co-makers. Changing customer requirements make it difficult to maintain a good working relationship. New contract types are an important means to optimize the supply chain (Akintoye et al., 2000). Given the long lifespan of building projects, contacts between the customer and the construction firm will differ from those in the car industry, where cars are traded in every 5-10 years.

2.5 Womack’s indicators and construction

We have already looked at the elements used by Womack et al. in terms of the different stages in the construction process. The question now is whether the indicators in the car industry can also be applied to construction. As mentioned already, the indicators used by Womack et al. are shown in table 2.3, column CAR.

Table 2-2, column Building provides a starting point, which originated from a pilot study.
### Table 2-2 Indicators used by Womack et al. versus construction first study.

<table>
<thead>
<tr>
<th>Parameter assembly plant</th>
<th>Vehicle</th>
<th>Building</th>
<th>Translated to construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Hours/vehicle</td>
<td>Hours/building</td>
<td>Building production</td>
</tr>
<tr>
<td>Engineering hours per new car</td>
<td>Hours/car</td>
<td>Hours/building</td>
<td>Engineering time new building</td>
</tr>
<tr>
<td>Engineering by suppliers</td>
<td>% Total hours</td>
<td>Hours/building</td>
<td>Engineering by suppliers</td>
</tr>
<tr>
<td>Development time per new car</td>
<td>Months/car</td>
<td>Months/building</td>
<td>Development time new building</td>
</tr>
<tr>
<td>Supplier proprietary parts (supplier’s own parts, e.g. Bosch ignition)</td>
<td>%</td>
<td>%</td>
<td>Supplier proprietary (electricity switch boxes) parts</td>
</tr>
<tr>
<td>Black box parts (standard parts)</td>
<td>%</td>
<td>%</td>
<td>Black box parts</td>
</tr>
<tr>
<td>Assembler designed parts</td>
<td>%</td>
<td>%</td>
<td>Assembler designed parts</td>
</tr>
<tr>
<td>Employees on project team</td>
<td>Person/team</td>
<td>Person/team</td>
<td>Employees on project team</td>
</tr>
<tr>
<td>New model</td>
<td>Body types/new car</td>
<td>Variation/building</td>
<td>Standard variation of home</td>
</tr>
<tr>
<td>Lead time prototype</td>
<td>Months/car</td>
<td>Months</td>
<td>Time from design till realization</td>
</tr>
<tr>
<td>Lead time start production &gt;&gt;&gt; sales</td>
<td>Months</td>
<td>Months</td>
<td>Time from start till 1st completion</td>
</tr>
<tr>
<td>Return to normal productivity after new model</td>
<td>Months</td>
<td>Months</td>
<td>Apprentice time</td>
</tr>
<tr>
<td>Engineering change costs as share of total die costs</td>
<td>% total</td>
<td>% total</td>
<td>Engineering change costs of resources (e.g. adjusting steel formwork when casting concrete in situ)</td>
</tr>
<tr>
<td>Die development time</td>
<td>Months</td>
<td>Months</td>
<td>Development time of resources (e.g. steel form in construction in concrete)</td>
</tr>
<tr>
<td>Die change time</td>
<td>Minutes</td>
<td>Hours/home</td>
<td>Change time important resource (e.g. change steel framework from ground floor to 1st floor)</td>
</tr>
<tr>
<td>Lead time new dies</td>
<td>Weeks</td>
<td>Weeks/home</td>
<td>Making new resource (e.g. steel framework)</td>
</tr>
<tr>
<td>Number of employees on project team</td>
<td>Employees</td>
<td>Employees</td>
<td>Number of employees on the project team</td>
</tr>
<tr>
<td>Supplier share of engineering</td>
<td>% total</td>
<td>% total</td>
<td>Supplier share of engineering</td>
</tr>
<tr>
<td>Ratio of shared parts</td>
<td>% total</td>
<td>% total material costs</td>
<td>Use of standardized products</td>
</tr>
<tr>
<td>Job classifications</td>
<td>Number</td>
<td>Number</td>
<td>Producing suppliers</td>
</tr>
<tr>
<td>Machines per employee</td>
<td>Number</td>
<td>Hours/€</td>
<td>Machine application in hours and €</td>
</tr>
<tr>
<td>Inventory levels</td>
<td>Days</td>
<td>€</td>
<td>Inventories</td>
</tr>
<tr>
<td>Inventory level for eight parts</td>
<td>Days</td>
<td>Days/object</td>
<td>Inventories for essential material (e.g. casing, lime components, wooden beams, sheets of wood, mortar in bulk)</td>
</tr>
<tr>
<td>Daily JIT deliveries</td>
<td>Number</td>
<td>Number</td>
<td>Daily JIT deliveries (e.g. ready mixed mortar for concrete and brickwork, prefab floor slabs, prefab floor-laying, hinge roofs, etc.)</td>
</tr>
<tr>
<td>Proportion of parts delivered just-in-time (JIT)</td>
<td>%</td>
<td>%</td>
<td>Proportion of parts delivered JIT of total delivery</td>
</tr>
<tr>
<td>Proportion of parts single sourced</td>
<td>%</td>
<td>%</td>
<td>Proportion of parts single sourced</td>
</tr>
<tr>
<td>Car sales per dealer</td>
<td>Number</td>
<td>Number</td>
<td>Built homes per contractor</td>
</tr>
<tr>
<td>Production and capacity vehicles</td>
<td>Number</td>
<td>Number/company</td>
<td>Production of homes per company</td>
</tr>
<tr>
<td>Parameter managing enterprise</td>
<td>Parameter design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter customer</td>
<td>Parameter assembly plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parameter supply chain (comparison suppliers)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How do we read these indicators from the perspective of a builder and what would the equivalent indicators be?
Table 2-3 Indicators used by Womack et al., (Womack et al., 2007) and construction.

<table>
<thead>
<tr>
<th>CAR</th>
<th>CONSTRUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Productivity</strong> (hours/vehicle)</td>
<td>Productivity hours/building</td>
</tr>
<tr>
<td><strong>Quality</strong> (assembly defects/100 vehicles)</td>
<td>Defects/completion</td>
</tr>
<tr>
<td>Space (sq. ft./vehicle/year)</td>
<td>Building site (all costs/m²/week).</td>
</tr>
<tr>
<td>Size of repair area (as % of assembly space)</td>
<td>Extending building site costs (as % of total site costs)</td>
</tr>
<tr>
<td>Absenteeism</td>
<td>Absenteeism</td>
</tr>
<tr>
<td><strong>Realization</strong></td>
<td></td>
</tr>
<tr>
<td>Engineering hours/10³ cars</td>
<td>Engineering hours/home</td>
</tr>
<tr>
<td>Development time/car (months)</td>
<td>Development time/home</td>
</tr>
<tr>
<td>Employees/project team</td>
<td>Employees/project team</td>
</tr>
<tr>
<td>Supplier share of engineering</td>
<td>Supplier share of engineering</td>
</tr>
<tr>
<td>Ratio of delayed products</td>
<td>Ratio of delayed products</td>
</tr>
<tr>
<td>Die development time (months)</td>
<td>Special resource development time</td>
</tr>
<tr>
<td>Time from production start to first sale (months)</td>
<td>Time from production start to first sale (months)</td>
</tr>
<tr>
<td><strong>Product development</strong></td>
<td></td>
</tr>
<tr>
<td>Die change time (minutes)</td>
<td>Special resource change time</td>
</tr>
<tr>
<td>Lead time for new dies (weeks)</td>
<td>Lead time for new resources</td>
</tr>
<tr>
<td>Machines/employee</td>
<td>Employees/machine</td>
</tr>
<tr>
<td>Inventory levels (days)</td>
<td>Inventory levels (days)</td>
</tr>
<tr>
<td>No. of daily JIT deliveries</td>
<td>No. of daily JIT deliveries</td>
</tr>
<tr>
<td>Parts defects/car</td>
<td>Defects/completion</td>
</tr>
<tr>
<td>Engineering performed by suppliers (% total hours)</td>
<td>Engineering performed by suppliers (% total hours)</td>
</tr>
<tr>
<td>Suppliers/assembly plant</td>
<td>Suppliers/building site</td>
</tr>
<tr>
<td>Inventory level (days, for eight parts)</td>
<td>Average inventory level €</td>
</tr>
<tr>
<td>Proportion of parts delivered just in time (%)</td>
<td>Proportion of parts delivered just in time (%)</td>
</tr>
<tr>
<td>Proportion of parts single sourced (%)</td>
<td>Proportion of parts single sourced (%)</td>
</tr>
<tr>
<td><strong>Suppliers</strong></td>
<td></td>
</tr>
<tr>
<td>Car sales/dealer</td>
<td>Home sales/franchiser</td>
</tr>
</tbody>
</table>

Now that we have outlined an initial set of equivalent indicators for (lean) construction, the next question is: how could we verify and supplement them in a sound manner?
3. Expert panel

3.1 Definition of an expert panel

An expert panel comprises a number of people who have extensive skills or knowledge in a particular field (Slocum, 2003). The description used by the Joint Research Centre of the European Commission states: “The expert panel method is based on the idea of eliciting expert knowledge”. There are several forms of composition for expert panels.

3.2 Task of an expert panel

Usually, the main task of an expert panel is to synthesize a variety of inputs, e.g. testimony, research reports, the output of forecasting methods, etc., and produce a report that presents a vision and/or recommendations for future possibilities along with the requirements for the topics being analyzed. Specific tools may be employed to select and motivate the panel, to assign tasks and to encourage the sharing and further development of knowledge (Slocum, 2003).
3.3 When can an expert panel be used

Expert panels are particularly useful for issues that require highly technical knowledge and/or are highly complex and require the synthesis of experts from different disciplines. This method is not designed to actively involve a broad selection of the public (Slocum, 2003). The result of the expert panel’s assessment is expressed in a revised list of indicators.

3.4 Composition of the expert panel

The panel comprised members of ENCORD’s Lean Construction Working Group. ENCORD is the European Network of Construction Companies for Research and Development. The panel members come from over all Europe, have a third level education and are all involved in lean construction in a professional capacity. The panel members meet the above-mentioned requirements as can be seen in table 3-1.
<table>
<thead>
<tr>
<th>Your specialist field (tick off)</th>
<th>Your company name</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Non-resid.</td>
<td>Civil</td>
</tr>
<tr>
<td>According to the Dutch system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GROUP 1 - RED**

- **X X X X** Ballast Nedam IR. Lean Manager
- **X X** Hochtief Solutions DR. Head of Quality and Lean Construction
- **X** Hilti Corporation DR. R&D Trends and Application
- **X X X X** BAM Nuttall IR. Director of Business Processes/Sustainability
- **X X X X X** CCC ING. Group Plant Manager - Operations
- **X X X X X** Vinci DR. R&D Coordinator

**GROUP 2 - ORANGE**

- **X X X X X** BAM Nuttall IR. Head of Quality
- **X X X X** Strabag DR. Business Unit Manager - Lean Construction
- **X X X X** Züblin IR. Project Manager - Planning
- **X X X X** Ferrovial DRS. Project Manager - R&D

**GROUP 3 - BLUE**

- **X X X X** Züblin IR. Project Engineer - Work Preparation
- **X X** YIT DR. R&D Manager - HVAC Technology
- **X X** Hochtief Solutions IR. Construction Management - services/Planning & Logistics
- **X** BAM Deutschland IR. Construction Manager
- **X** TU/E ING. Researcher/Construction Manager

**GROUP 4 - GREEN**

- **X** Strabag DR. Lean Academy
- **X X X X X** Ferrovial MR. Head of International Projects - R&D
- **X** NCC DR. Manager of Process Development/Researcher
- **X** GTM IR. Manager of Integrated Quality
- **X** GTM batiment ING. Lean Construction Manager
- **X** BAM/TU/e PROF. Strategy/Building processes

Table 3-1 Members of the expert panel and their expertise.
3.5 Web meetings

Table 2-3 should be taken as the starting point for the work done by the expert panel.

Given that the experts work in different fields, we took the opportunity to distinguish between the different types of construction (projects). The new groups are: residential, non-residential, civil engineering, bridges, roads and railroads. The indicators we were most interested in were those related to efficiency and effectiveness. There may be a lot, but they can later be pooled. The elements relating to efficiency primarily concern the following: labor, material, equipment and sub-contractors. Capital is of course an important factor too and is also mentioned by Womack et al. (Krafcik, 1988).

During each web meeting we addressed, discussed and supplemented one of the following stages:
- Assembly plant - construction site
- Product development - design
- Suppliers - partners - co-makers - subcontractors
- Customer

The following question was also asked: how could we measure the value of the indicators? The four interim results were combined, weighted and supplemented later on in a plenary meeting of the expert panel.
4. Results

Table 4-1 Final list of indicators for ENCORD members from the lean meeting in Paris on March 19-20, 2013. The different colors refer to the separate discussion groups. The results are a direct representation of what was discussed in the four groups, so there may be duplications. Text in red means group RED, text in orange means group ORANGE, text in blue means group BLUE and text in green means group GREEN.

Table 4-1 Shows the overall result of the meetings.
Please note that this is one table although it is spread over the following pages.

<table>
<thead>
<tr>
<th><strong>ASSEMBLY PLANT - CONSTRUCTION SITE</strong></th>
<th><strong>CAR assembly</strong></th>
<th><strong>BUILDING construction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Productivity</strong> (hours/vehicle)</td>
<td>Productivity hours/building. This measure is usually expressed as total costs/total labor costs. Another possibility is the productivity per part of a project, e.g. foundation, skeleton, outside walls, etc.</td>
<td>Labor, direct* and indirect** working hours, time. *=directly spent on the product, **=indirectly spent on the product.</td>
</tr>
<tr>
<td></td>
<td>Labor turnover (literally staff changes, but we meant total costs of labor in €). You can also relate these costs of labor to the total processed project costs. Also regarding the direct and indirect costs.</td>
<td>Total of labor costs. Total project costs processed.</td>
</tr>
<tr>
<td></td>
<td>Takeaways. Make a record of the number of takeaways related to something going wrong (= failures/defects) or record the training opportunities.</td>
<td>Number of defects. Number of training opportunities, e.g. toolbox meetings, explanation when using new equipment, machinery or methods.</td>
</tr>
<tr>
<td></td>
<td>Measuring labor stability - same employees as week before. This is in fact labor turnover.</td>
<td>Number of employees and staff changes.</td>
</tr>
<tr>
<td></td>
<td>Constructability.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reach objectives.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time spent on looking for material/equipment.</td>
<td></td>
</tr>
</tbody>
</table>
### ASSEMBLY PLANT - CONSTRUCTION SITE

<table>
<thead>
<tr>
<th>CAR assembly</th>
<th>BUILDING construction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td>Flow indicator</td>
<td></td>
</tr>
<tr>
<td><strong>No waiting time.</strong></td>
<td>Waiting time can arise because of missing materials and equipment or if a previous activity is not finished on time.</td>
</tr>
<tr>
<td><strong>Changes to schedule. Changes to schedule. Plan changes.</strong></td>
<td>The reason for the changes, e.g. caused by the client (e.g. waiting for information or changing the plan) or by the contractor (e.g. poor scheduling, making mistakes, not enough staff, the wrong staff, etc.).</td>
</tr>
<tr>
<td>Plant turnover.</td>
<td>Manufactured in €.</td>
</tr>
<tr>
<td>In relation to equipment.</td>
<td>Machinery time used.</td>
</tr>
<tr>
<td>In relation to situation (point and line project).</td>
<td>The situation of the site and the government regulations for the area must be considered when setting prices. There are a lot of parameters. Perhaps it is possible to weight every parameter and come up with one indicator.</td>
</tr>
<tr>
<td><strong>Weekly completion in %. PPC value in %. Stages of production.</strong></td>
<td>Completed activities.</td>
</tr>
<tr>
<td><strong>Re-do work. Re-do work. Re-do work.</strong></td>
<td>Labor time and material costs. Number of incorrect constructions.</td>
</tr>
<tr>
<td><strong>Cost of rework. Cost of defects.</strong></td>
<td>Queries on rework.</td>
</tr>
<tr>
<td><strong>Could be measured by categorized queries in day sheets.</strong></td>
<td></td>
</tr>
<tr>
<td>Additional work.</td>
<td>Amount of labor and material.</td>
</tr>
<tr>
<td><strong>Different phases of delivery.</strong></td>
<td>JIT deliveries.</td>
</tr>
<tr>
<td><strong>Balance of performance-based salaries.</strong></td>
<td>Manager's performance in terms of trying to keep to previously made agreements. A well-thought-out salary system.</td>
</tr>
<tr>
<td><strong>Measure of time lost on machines or because of road work.</strong></td>
<td>Amount of time lost on machines or because of road works.</td>
</tr>
<tr>
<td><strong>Develop a scanning system for the delivery papers.</strong></td>
<td>Paper flow.</td>
</tr>
<tr>
<td><strong>Lost time quality audits (e.g. twice a week to measure lost time according to various criteria. What are the defects, where, etc.?</strong></td>
<td>Variations.</td>
</tr>
<tr>
<td><strong>Competition, who is the best?</strong></td>
<td>Depends on the group.</td>
</tr>
</tbody>
</table>
# ASSEMBLY PLANT – CONSTRUCTION SITE

<table>
<thead>
<tr>
<th>CAR assembly</th>
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<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td><strong>Quality</strong> (assembly defects/100 vehicles)</td>
<td></td>
</tr>
<tr>
<td>Defects/completion.</td>
<td>Not applicable.</td>
</tr>
<tr>
<td><strong>Not only at the end.</strong></td>
<td>Number of defects after a completed activity. And repair time.</td>
</tr>
<tr>
<td><strong>For every milestone.</strong></td>
<td>Number of defects by a defined point of time. And repair time.</td>
</tr>
<tr>
<td>Space (sq. ft./vehicle/year)</td>
<td>Building site (all costs/m²/week).</td>
</tr>
<tr>
<td>Building site (all costs/m²/week).</td>
<td>Site costs.</td>
</tr>
<tr>
<td><strong>Difference in % between residential, non-residential, bridges, roads and railroads.</strong></td>
<td>Site costs.</td>
</tr>
<tr>
<td>Non-conformities.</td>
<td>Number and costs to repair.</td>
</tr>
<tr>
<td><strong>Transparency.</strong></td>
<td>Extensive site administration.</td>
</tr>
<tr>
<td><strong>Quality, time, costs.</strong></td>
<td>Extensive site administration.</td>
</tr>
<tr>
<td>Size of repair area (as % of assembly space)</td>
<td>Overrun time due to different delays related to lead time.</td>
</tr>
<tr>
<td>Increasing site costs (as % of total site costs).</td>
<td></td>
</tr>
<tr>
<td>Absenteeism</td>
<td>Absenteeism.</td>
</tr>
<tr>
<td>Absenteeism.</td>
<td>Staff absenteeism, are they really sick or is it the kind of work?</td>
</tr>
<tr>
<td>Safety on site.</td>
<td>Building site registration.</td>
</tr>
<tr>
<td><strong>Number of accidents.</strong></td>
<td></td>
</tr>
<tr>
<td>1-3 days off work.</td>
<td></td>
</tr>
<tr>
<td>More than 3 days off work.</td>
<td></td>
</tr>
<tr>
<td>Death/invalid.</td>
<td></td>
</tr>
</tbody>
</table>
### PRODUCT DEVELOPMENT - DESIGN

<table>
<thead>
<tr>
<th>CAR assembly</th>
<th>BUILDING construction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td>Engineering hours/10^3 cars</td>
<td>Engineering hours/(home) <em>per value of project</em>.</td>
</tr>
<tr>
<td>Value of the project in € (£).</td>
<td>Total of engineering costs.</td>
</tr>
<tr>
<td>Distance for road and rail construction.</td>
<td>Specific measure of the project.</td>
</tr>
<tr>
<td>Relationship between engineering and construction.</td>
<td>Engineering costs versus construction costs.</td>
</tr>
<tr>
<td>Number of standard details versus specific details.</td>
<td>The proportion of standard details versus specific details.</td>
</tr>
<tr>
<td>Energy (CO₂).</td>
<td>Special preparations to reduce CO₂ in engineering time.</td>
</tr>
<tr>
<td>Development time/car (months)</td>
<td>Development time (design and planning)/home.</td>
</tr>
<tr>
<td>The number of changes in design <em>after final design</em>.</td>
<td>Design changes after final design.</td>
</tr>
<tr>
<td>By the customer (failures, mistakes.)</td>
<td>Design changes due to design mistakes.</td>
</tr>
<tr>
<td>By the environment.</td>
<td>Design changes due to the environment.</td>
</tr>
<tr>
<td>Revisions per drawing during and before construction.</td>
<td>Revisions per drawing during and before construction.</td>
</tr>
<tr>
<td>Seek additional information</td>
<td>Missing measures on drawings.</td>
</tr>
<tr>
<td>Delivery design in time. Late delivery of supplier’s design.</td>
<td>Milestones.</td>
</tr>
<tr>
<td>No changes in schedule.</td>
<td>Number of changes.</td>
</tr>
<tr>
<td>Clash detection.</td>
<td>Number of clashes.</td>
</tr>
<tr>
<td>At a certain point in time: final design=no changes. Up to that point, any changes should add value.</td>
<td>To assess by collaborate design and define the milestones.</td>
</tr>
<tr>
<td>Coordination with all disciplines.</td>
<td>Lead time of the collaborate design.</td>
</tr>
<tr>
<td>Time of revision before and after approval.</td>
<td>Days of revision.</td>
</tr>
</tbody>
</table>
## PRODUCT DEVELOPMENT - DESIGN

<table>
<thead>
<tr>
<th>CAR assembly</th>
<th>BUILDING construction</th>
</tr>
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<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td><strong>We need a plan of the plan.</strong></td>
<td>Headlines and structure of the project. Days of overrun according to schedule.</td>
</tr>
<tr>
<td><strong>Only start construction after a complete plan.</strong></td>
<td>Define this time and use extra time to make the plan complete for all members.</td>
</tr>
<tr>
<td><strong>Measure changes.</strong></td>
<td>Number of changes.</td>
</tr>
<tr>
<td><strong>Focus on the process. Number of defects.</strong></td>
<td>Value stream mapping to draft an appropriate schedule. Number of differences.</td>
</tr>
<tr>
<td><strong>Quality lost.</strong></td>
<td>Specification of quality and inspection. Number of differences.</td>
</tr>
<tr>
<td>Employees/project team</td>
<td>Employees/project team (design team). Number of employees. Eventually per expertise.</td>
</tr>
<tr>
<td><strong>Value of the project (£/€). Report differences.</strong></td>
<td>Together with a project category as a rough draft. Project category and value of the project.</td>
</tr>
<tr>
<td><strong>Projects per employee.</strong></td>
<td>Is an indication of the size of a specific part in the design. It also says something about the project. Time spent.</td>
</tr>
<tr>
<td><strong>Costs saved on site/plant through good design/engineering.</strong></td>
<td>Difficult to measure. Compare money and time from the calculation with the real construction. The money and time calculated and the money and time actually spent.</td>
</tr>
<tr>
<td>Supplier share of engineering</td>
<td>Supplier share of engineering, % of suppliers design. The advantage is good design because they have the most practical experience with a system. The disadvantage is that it is difficult to compare with other systems. Number of suppliers in design and their trade.</td>
</tr>
<tr>
<td><strong>Number of leading suppliers for the design.</strong></td>
<td>When the suppliers that own a specific part are leading in the design, e.g. an escalator. Number of leading suppliers.</td>
</tr>
<tr>
<td><strong>Ratio of delayed products</strong></td>
<td>Ratio of delayed product drawings and other information. The starting point is the production start date when the design is completely ready. Is there a direct connection with other design disciplines? Delay to the critical path. Other delays per supplier.</td>
</tr>
<tr>
<td><strong>The right information at the right time. Waiting time.</strong></td>
<td>Is the information complete and on time (including preparation time? Time overrun. Waiting time.)</td>
</tr>
<tr>
<td>PRODUCT DEVELOPMENT - DESIGN</td>
<td>BUILDING construction</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>CAR assembly</td>
<td></td>
</tr>
<tr>
<td>What and how to measure</td>
<td>What to measure during the process</td>
</tr>
<tr>
<td>Interoperability in % of process covered by BIM.</td>
<td>Has BIM been used and for what parts of the process? What parts of the process are covered by BIM?</td>
</tr>
<tr>
<td>Die development time (months)</td>
<td>Special resource development time.</td>
</tr>
<tr>
<td>Time between development and the start of production.</td>
<td>Design time. Time of start of realization.</td>
</tr>
<tr>
<td>Time from production start to first sale (months)</td>
<td>Time from production start to first sale (delivery).</td>
</tr>
<tr>
<td>Quicker with same resources, no use of additional resource.</td>
<td>Are resources standard or custom made for the project?</td>
</tr>
<tr>
<td><strong>SUPPLIERS - PARTNERS - CO-MAKERS - SUBCONTRACTORS</strong></td>
<td><strong>CAR assembly</strong></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td>Die change time</td>
<td>Special resources change time.</td>
</tr>
<tr>
<td></td>
<td><strong>Material/equipment suitable for site/plant.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Modular design.</strong></td>
</tr>
<tr>
<td>Lead time for new dies</td>
<td>Lead time new resources.</td>
</tr>
<tr>
<td>May not be suppliers better in building sites</td>
<td>Adapting resources (e.g. formwork).</td>
</tr>
<tr>
<td></td>
<td><strong>Re-handling materials on site.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>One schedule for every discipline (suppliers, designers, contractors).</strong></td>
</tr>
<tr>
<td></td>
<td><strong>A more quality schedule.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Number of tasks in a schedule/number of suppliers.</strong></td>
</tr>
<tr>
<td></td>
<td><strong>What can the supplier do to improve the results of the whole project?</strong></td>
</tr>
<tr>
<td>Machines/employees</td>
<td>Machines/employees.</td>
</tr>
<tr>
<td></td>
<td><strong>Workers/employees.</strong></td>
</tr>
</tbody>
</table>
### SUPPLIERS - PARTNERS - CO-MAKERS - SUBCONTRACTORS

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td><strong>Inventory levels (days)</strong></td>
<td>Inventory levels (days or €) on site or assistance site.</td>
</tr>
<tr>
<td></td>
<td>What is the minimum of inventory required to ensure a continuous process? Inventory level.</td>
</tr>
<tr>
<td><strong>The relationship, connection is important</strong></td>
<td>Schedule the JIT&gt;&gt;&gt; draw up a timetable. Handling of materials/equipment in the supply chain. Depends on: storage area, how often you need the material, risk and delivery time (criteria) of the materials.</td>
</tr>
<tr>
<td></td>
<td>Material and resource schedule. Number of defects over time.</td>
</tr>
<tr>
<td><strong>Rework.</strong></td>
<td>Try to prevent (stop) rework by automation. Try to stop and repair rework as soon as possible. Number of rework instances. Cost (€) of rework.</td>
</tr>
<tr>
<td><strong>No. of daily JIT deliveries</strong></td>
<td>No. of daily JIT deliveries (incorrect and damaged deliveries).</td>
</tr>
<tr>
<td></td>
<td>JIT deliveries are only possible when the schedule is managed and updated on an ongoing basis. Number of defects over time.</td>
</tr>
<tr>
<td><strong>Late deliveries.</strong></td>
<td>Quality of deliveries, in time, incorrect, damaged. Number of incorrect deliveries.</td>
</tr>
<tr>
<td><strong>Long-term partnership.</strong></td>
<td>Comakership is a very good way to work together because of the open contact and the longterm contact. Number of comakers and trade.</td>
</tr>
<tr>
<td><strong>Parts defects/car</strong></td>
<td>Defects/completion.</td>
</tr>
<tr>
<td></td>
<td>This indicator is used a lot. The advantage is that it only counts at the end of the process. Number of defects. Cost of repair. Time of repair.</td>
</tr>
<tr>
<td><strong>Defects during the process (time, costs, number). How many defects? Not only for the suppliers.</strong></td>
<td>Defects during the process tend to be much more expensive than at completion. Number of defects. Costs of repair. Time of repair.</td>
</tr>
<tr>
<td><strong>Chain of subcontractors (sub, sub, sub).</strong></td>
<td>When poor agreements are made this can lead to problems, a situation that can be seen more and more. Number of suppliers and sub - suppliers.</td>
</tr>
<tr>
<td><strong>Number of defects&gt;&gt;&gt;in relation to zero defects.</strong></td>
<td>This Six Sigma approach matches the above parameter; defects during the process.</td>
</tr>
<tr>
<td><strong>Continually improve.</strong></td>
<td>Treat suppliers as if they were your own staff and support them. Use performance interviews to do so. Calculate scores using performance interviews.</td>
</tr>
<tr>
<td><strong>Number of standardized levels of quality control.</strong></td>
<td>Quality control is most valuable when quality has been defined before. Deviations can be recorded. Number of quality deviations.</td>
</tr>
<tr>
<td>CAR assembly</td>
<td>BUILDING construction</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td><strong>Job satisfaction.</strong></td>
<td>A very important item. One of the indicators is absenteeism. Performance interviews can be held for the staff in question. Calculate the results.</td>
</tr>
<tr>
<td>Suppliers/assembly plant</td>
<td>Suppliers/buildingsite <strong>specialization.</strong></td>
</tr>
<tr>
<td>Suppliers/supplier, <strong>chain of suppliers, team approach.</strong></td>
<td>When poor agreements are made this can lead to problems, a situation that can be seen more and more. Number of suppliers and sub - suppliers.</td>
</tr>
<tr>
<td>Inventory level (days, for eight parts)</td>
<td>Average inventory level €.</td>
</tr>
<tr>
<td><strong>Common goals/objectives.</strong></td>
<td>These goals can be set if there is a good scheduling system.</td>
</tr>
<tr>
<td><strong>IPD share profit/costs.</strong></td>
<td>What is the relationship between costs and profit, between JIT delivery and the average inventory level? Costs of average inventory. Costs of inventory when using JIT as much as possible.</td>
</tr>
<tr>
<td>Proportion of parts delivered just in time (%)</td>
<td>Proportion of parts delivered just in time (%)</td>
</tr>
<tr>
<td>Complaints against each other.</td>
<td></td>
</tr>
<tr>
<td><strong>Type of contract.</strong></td>
<td>The type of contract establishes how free the contractor can be in their actions. In a traditional contract, everything has been specified. Freedom of action should be seen as a good way for the company to choose the most efficient way of construction that suits the company. <strong>Type of contract.</strong></td>
</tr>
<tr>
<td><strong>The impact of materials that are not delivered on time (software- based).</strong></td>
<td>Value stream mapping to identify this. Number of missing materials and services. Cost of missing materials and services.</td>
</tr>
<tr>
<td>SUPPLIERS - PARTNERS - CO-MAKERS - SUBCONTRACTORS</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>CAR assembly</strong></td>
<td><strong>BUILDING construction</strong></td>
</tr>
<tr>
<td>What and how to measure</td>
<td>What to measure during the process</td>
</tr>
<tr>
<td>Proportion of parts single sourced (%)</td>
<td>Proportion of parts single sourced (%). Parts that need special treatment not suitable for the normal process. Number of parts single sourced. Cost of parts single sourced.</td>
</tr>
<tr>
<td>Reliability of what is promised (delivery time).</td>
<td>Can you count on the supplier? Here, the co-maker is important because they have more of a connection with the company. They consider the long term. Number of deliveries of materials and services not in time. Cost of late deliveries.</td>
</tr>
<tr>
<td>Communication</td>
<td>Communication: what is efficient for supplier/subcontractor?</td>
</tr>
<tr>
<td></td>
<td>Efficiency can be translated, so that work can be done in as little time and using as little money as possible. That is why it does not make any sense if it concerns the contractor, supplier or subcontractor. In practice, a supplier needs all the information in time and a healthy working relationship with the other parties. Issues with information delivery.</td>
</tr>
<tr>
<td>Orders/day.</td>
<td>To me, orders a day seems more like something for small suppliers working per hour. However, maybe it means that receiving too many instructions every day at one time makes it difficult for the staff to remember and that this is why they will sooner make mistakes. Orders per time per employee.</td>
</tr>
<tr>
<td>Flow</td>
<td>Flow: batch versus one piece.</td>
</tr>
<tr>
<td></td>
<td>A batch is a manageable group of goods produced in one process step. One aspect of flow is individual production, i.e. one piece is finished before another piece is started. One piece flow is in combination with the pull system. An important aspect of one piece flow is the takt time or meter.</td>
</tr>
</tbody>
</table>
### CUSTOMER

<table>
<thead>
<tr>
<th>CAR assembly</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td>Car sales/dealer</td>
<td>Home sales/franchiser.</td>
</tr>
<tr>
<td></td>
<td>Units of production per dealer. From the customer side, you can view the dealer as a project.</td>
</tr>
<tr>
<td>Who is the customer?</td>
<td>A customer or client is a person or organization that receives goods or services from another person or organization. Take a look at your customer and find out what they really want and what you can do for them. Ask the customer.</td>
</tr>
<tr>
<td>What are our goals?</td>
<td>There is one primary goal, a satisfied customer. This goal can be divided in several sub-goals, depending on the current status of the company. Toyota sets a much larger goal and thinks of the company and its staff in the future.</td>
</tr>
<tr>
<td>What are the common goals?</td>
<td>Whose common goals? Departments, suppliers and staff, etc. should all share the same goal, i.e. to have a satisfied customer.</td>
</tr>
<tr>
<td>END USER is not known with all kinds of issues.</td>
<td>The end user must be seen as the customer. They must get what they expect or may expect in the light of what is normal or what they pay for.</td>
</tr>
<tr>
<td>CLIENT is the one who is paying you.</td>
<td>They have different expectations than the customer/end user. Although their expectations are different, they must also get what they expect to get from their customers. You have to investigate what this is. You can do it before or after you work together. Client &lt;&gt; Customer?</td>
</tr>
<tr>
<td>Client represents the end user and vice versa.</td>
<td>The client has to take two interests into account.</td>
</tr>
<tr>
<td>CAR assembly</td>
<td>BUILDING construction</td>
</tr>
<tr>
<td>------------------------------</td>
<td>----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>What and how to measure</strong></td>
<td><strong>What to measure during the process</strong></td>
</tr>
<tr>
<td>Lost, quality, time, defects, claims, safety, environment.</td>
<td>All of these indicators are required to be able to define the customer value.</td>
</tr>
<tr>
<td>Certification, references, sustainability with other projects.</td>
<td></td>
</tr>
<tr>
<td>Local employees, production and impact or intension.</td>
<td></td>
</tr>
<tr>
<td>Link budget-schedule.</td>
<td></td>
</tr>
<tr>
<td>Profitable turnover.</td>
<td></td>
</tr>
<tr>
<td>Understanding of needs.</td>
<td></td>
</tr>
<tr>
<td>Transparency with the client.</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation score:</strong></td>
<td><strong>From 1-5 on the Likert scale.</strong></td>
</tr>
<tr>
<td>This is a way of expressing the value of the customer.</td>
<td></td>
</tr>
<tr>
<td>Own contribution.</td>
<td>What is a customer willing to do on their own?</td>
</tr>
<tr>
<td>Demands.</td>
<td>What does a customer ask for?</td>
</tr>
<tr>
<td>Expectation.</td>
<td>What does a customer expect?</td>
</tr>
<tr>
<td>Count the number of meetings with the customer to establish expectations.</td>
<td>All of these points are merely further interpretations of the above-mentioned points.</td>
</tr>
<tr>
<td>Depends on stage of the construction process.</td>
<td></td>
</tr>
<tr>
<td>Indicator following orders.</td>
<td></td>
</tr>
<tr>
<td>Satisfaction for the customer/client.</td>
<td></td>
</tr>
<tr>
<td>Service is important.</td>
<td></td>
</tr>
<tr>
<td>Questionnaire about satisfaction.</td>
<td></td>
</tr>
</tbody>
</table>
### CUSTOMER

**CAR assembly** | **BUILDING construction**

<table>
<thead>
<tr>
<th>What and how to measure</th>
<th>What to measure during the process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery on time/earlier.</td>
<td></td>
</tr>
<tr>
<td>Client involvement.</td>
<td></td>
</tr>
<tr>
<td>Trust, clear and stable.</td>
<td></td>
</tr>
<tr>
<td>Progress.</td>
<td></td>
</tr>
<tr>
<td>Finance: within budget.</td>
<td></td>
</tr>
<tr>
<td>In a perfect world, a lean organization can deliver a better, faster and cheaper project.</td>
<td></td>
</tr>
<tr>
<td>Long-term customer/client image.</td>
<td></td>
</tr>
<tr>
<td>Service.</td>
<td></td>
</tr>
<tr>
<td>If client is happy, they will come back.</td>
<td></td>
</tr>
<tr>
<td>Measurement of complaints.</td>
<td></td>
</tr>
<tr>
<td>Time to being resolved (standard process).</td>
<td></td>
</tr>
<tr>
<td>Response time.</td>
<td></td>
</tr>
<tr>
<td>One contact person for the customer.</td>
<td></td>
</tr>
<tr>
<td>Service for operation.</td>
<td></td>
</tr>
<tr>
<td>Major difference, customer tells us what to do in a more unique way.</td>
<td></td>
</tr>
<tr>
<td>Number of change orders.</td>
<td></td>
</tr>
<tr>
<td>In the construction process, impact decreases with time depending on how far down the line you are.</td>
<td></td>
</tr>
<tr>
<td>Think also about the internal customer.</td>
<td></td>
</tr>
<tr>
<td>How do we measure demands, expectations and satisfaction internally?</td>
<td></td>
</tr>
</tbody>
</table>
5. Conclusion

The method of measuring and comparing used by Womack et al. (Womack et al., 2007) in their study, and which is outlined in the book TMTCTW, can also be used for building projects. The extensive list of indicators drawn up by the expert panel shows this.

As indicated by Womack et al., the advantages they found for assembly plants are therefore also suitable for application in other all industries, including construction.

The most important indicators for a building project are productivity and quality. In the case of production, we can see that time is the leading factor. In the case of quality, it is cost that is the key factor, while time, again, is a key factor in the case of repairs and stagnation caused by poor quality. In fact, the same characteristics apply for each element. In the case of the customer, the direct impact of these characteristics is the least important, while the indirect impact though pricing is all the more significant.

Acknowledgement
We are very grateful to the members of ENCORD’s Lean Construction Working Group, who participated in the expert panel, for their assistance and the information they provided.
References


