INDUSTRIALIZATION IN SWEDISH BRIDGE ENGINEERING: A CASE STUDY OF LEAN CONSTRUCTION

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ABSTRACT

The purpose of the project has been to evaluate and possibly improve the degree of industrialization and productivity when constructing bridges in full scale. Earlier theoretical studies have indicated that, if prefabricated reinforcement, self compacting concrete (SCC) and permanent formwork are used the degree of industrialization can be increased markedly. To be able to realize this, Lean Construction principles prove to be important utensils during the planning and design phase as well as during the construction of a full scale project.

Throughout the design and planning of this first full scale bridge project, intensive contacts between designer, contractor, client and material suppliers were established. The design team concluded that the production time at site could be reduced with up to 20 % and the number of workers could be reduced by virtually 50 % during almost half the project. This was realized by planning with Last Planner ideas, and designing the project properly using modern construction tools and materials. The design team also concluded that if the concrete class increased some of the very dense shear force reinforcement could be left out.

The evaluated outcome of the demonstration project, i.e. potential productivity improvements, structural quality improvements, immediate feasible waste and cost reductions and the positive impact on the working environment, shows that the predicted benefits made were fulfilled.

KEY WORDS. Bridge design, Concrete, Productivity, Industrialisation, Lean, Waste, Logistics, Full scale test, Prefabrication, Reinforcement

INTRODUCTION

The productivity of the building sector has been low when compared to other sectors, e.g. the manufacturing industry. *Industrialization* is often mentioned as the measure to be taken to increase the productivity and its definition is frequently debated in literature. It is agreed however that to achieve a more industrialized process, focus cannot only be on the production apparatus, i.e. the whole process needs to be managed from project idea to completed structure. Other important issues that must be addressed at an industrialization level are logistics, collaboration between partners, standardized concepts, prefabrication of highly processed components, information technology and Lean Construction

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philosophies (Olofsson et al, 2004) and (Byfors, 1999). Now, strong efforts are being taken by contractors towards industrialization and, the introduction of new methods to improve the design and planning processes as well as the production process are of great interest.

The platform for Lean Construction is simple: to deliver what the customer wants when he needs it in the quantity that he requires. A key issue is then the focus on the well known “muda”, i.e. any human activity that absorbs resources without creating any value (Womack and Jones, 2003). Muda includes: 1) overproduction, 2) waiting, 3) unnecessary transports, 4) erroneous processes, 5) unnecessary inventory, 6) unnecessary movement, 7) goods with errors and 8) to not meet customer needs. Another key criterion for Lean Construction is that downstream actors are involved upstream in decisions and vice versa. This means that stakeholders must involve contractors, material suppliers etc. as early as possible in a project maintaining a good contact throughout the entire project. This contact ensures that products and processes are designed in collaboration between partners.

Several tools and methods are available for planning, for instance applying Concurrent Engineering (CE) where resources are used effectively in cooperation between design, construction and production in cross functional working teams that are a part of the optimization of the planning process (Olofsson et al, 2004).

For the industrialization of construction with in-situ cast concrete focus must be on the following six components, (Figure 1):

- Improved concrete qualities and optimal construction e.g. SCC.
- Minimized reinforcement activities on site.
- Permanent and /or optimized formwork minimizing site logistics.
- Optimized concrete transport on site from the truck to form, e.g. pumping techniques.
- Weather independent construction processes, e.g. climate protective tent.
- IT and Lean construction tools, where multi-disciplinary decisions are made at design, production planning, and construction e.g. reducing muda.

OBJECTIVE OF THE RESEARCH PROJECT

The following general research questions have been defined of the PhD research project “Industrial concrete bridge construction” at Luleå University of Technology:

-*Who owns the industrialization question?*

-*When should the industrialization process start?*

-*How should industrialization be implemented in the design and construction phase?*

-*What are the existing problems, if any, hindering the introduction of industrialization?*

-*What are the main obstacles for introducing Lean Construction, and can industrialization be introduced applying lean construction in civil engineering?*

-*Where can we find new solutions for existing problems?*

Further more it is known that the earlier in a projects design and execution phase industrialization ideas can be introduced, the greater the influence will be, Table 1.

Table 1: Typical process for construction of larger civil engineering structures, e.g. bridges, and necessary early introduction of industrialization.

Phase	**Preliminary study**	**Feasibility study**	**Design plan**	**Purchasing**	**Building documents**	**Execution**	**Operation/ maintenance**
Remark	Needs, demands etc	Alternative routes	Designing the layout	Entrepreneur involved	Detailed design		
Outcome		Collaborate bridge types Aesthetics within limits Create conditions for industrialztion	Geometrical prerequisites, Banking → cambering etc Create conditions for industrialztion Aesthetics etc	Supply conditions Matrl conditions	Documents	Building process	Continued collaboration between contractor and client?
Possible influence industrialz		Important step for industrialization! Most influence	Important step for industrialization! Less influence	Important step for industrialization! Less influence	Might be too late!	Too late	

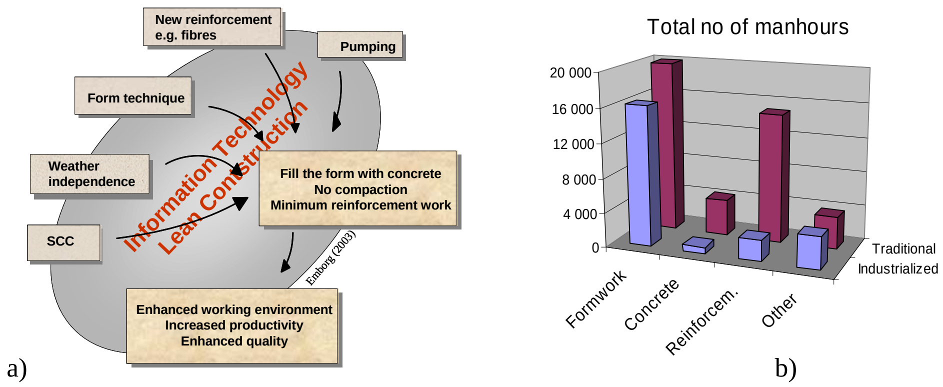


Figure 1: a) Industrial site cast construction by integrating material and production techniques with IT and Lean Construction (Emborg et al, 2005) b) Theoretical on-site time savings when applying industrial construction on bridge projects in Sweden (permanent formwork only partly).

THEORETICAL PILOT STUDIES

One focus of the research is to see which parts of a bridge that can conveniently be prefabricated and which parts that must be manufactured traditionally on site. Therefore the project was initiated by following up some already constructed in-situ cast concrete bridges to identify areas where major advancements in production can be achieved. Reinforcement, formwork and in-situ casting of concrete typically make up for approximately 50 % of the total construction costs with relative ratios of approximately 1/3 (Simonsson and Emborg, 2005). The other 50 % of the costs is related to general establishment at the building site, foundation, pile driving, asphalting, railing etc. From a purely theoretical viewpoint, the implementation of industrialized construction methods can reduce the manpower substantially for these bridges, Figure 1b. For instance, if prefabricated reinforcement is used in the foundations and superstructure, the on-site construction time can be reduced with up to 80 %.

More over, besides the reduction of the number of man hours needed (Figure 1b), applying SCC will also increase the casting rates, and improve the working environment (Skarendahl, 2001).

THE FULL SCALE BRIDGE – LEAN CONSTRUCTION PLANNING

GENERAL

This part of the research, i.e. the full scale project is mainly dedicated to the two last research questions mentioned above, i.e. to examine what kind of possibilities of industrialization Lean Construction principles can provide when applied to civil engineering, and particularly to an in-situ cast concrete bridge project.

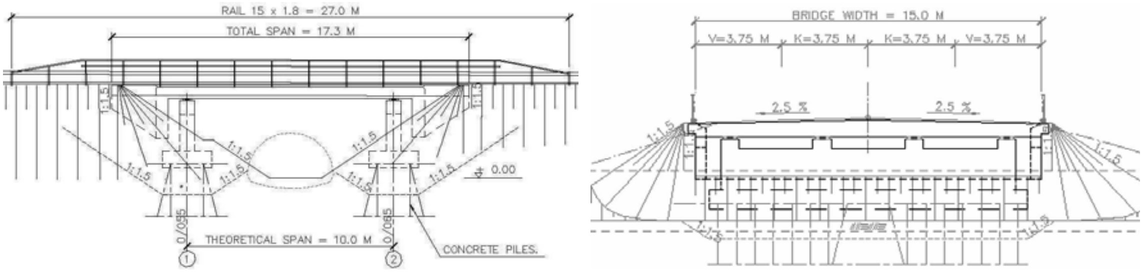


Figure 2: Full scale object in elevation and section (no scale).

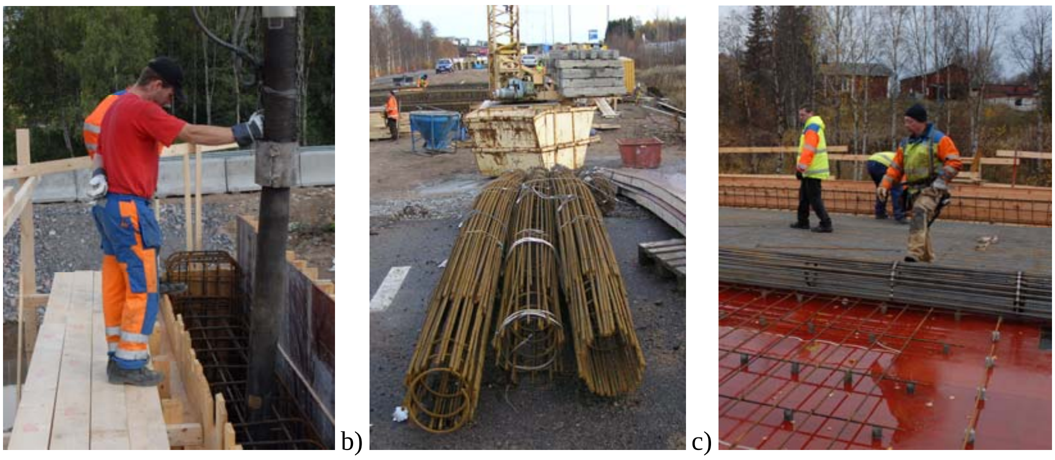
a) b) c)


Figure 3: a) Filling the plate structures with SCC, b) Carpet reinforcement for the superstructure, c) Mounting the carpet reinforcement on the superstructure.

The studied bridge *"the industrial concrete bridge"* consists of a span of 10 metres with a width of 15 metres, Figure 2. A key for the success was that the owner, contractor, material supplier and designer cooperated during the complete project. Thus, already during the design phase the partners agreed that SCC and prefabricated reinforcement for the foundations and for some of the superstructure should be used. It was also decided that carpet reinforcement (Figure 3 b and c) were to be used for the super structure and that Lean Construction principles should be utilized during both design and construction phases.

BRIDGE DESIGN FOR CUSTOMER VALUE

Customer value and satisfaction are central points in all types of production; as a result it is of great importance to understand customer needs and expectations before starting production. Crow and Barda, (2004) found in a study that contractors, designers and suppliers often focus on making profit instead of focusing on providing the end user service, this instead repeatedly has the opposite effect and results in economic losses.

According to Karlsson et. al (1998) it is important to implement/transfer customer needs and wishes into specifications for a product and let these specifications greatly influence the design phase of a project. The design documents ensure that the product will function as the customer requires. Considering customer value for a typical highway bridge project, the primary customer is the public. Specified value for a highway bridge is among other things: It should be trafficable, safe and comfortable at an appropriate velocity, have sufficient carrying capacity, and during construction cause as little disturbance on traffic as possible. It should be designed so that future inspection, maintenance and management are economical and easy to perform. The bridge should also be flexible for changes in traffic demand and it should harmonize with the surrounding landscape.

DESIGN PROCESS

When establishing a team meeting these criteria, i.e. a Lean Design Team, for the proper planning and design of the bridge, it is of great importance to include all areas of interest for the studied project. Therefore, knowledge from production, design, management, customer, suppliers and 3D and 4D modelling should actively be implemented in the design phase together with a close relation to the customer. The project team has a few design aids and technical solutions mentioned above i.e. prefabricated reinforcement and SCC to choose from.

The main designer, the prefabricated reinforcement designer/supplier and the concrete supplier worked together in cooperation with the contractor using the techniques of concurrent engineering to solve problems and to find possibilities in their different areas simultaneously. This thinking was settled at the first meeting of the Lean Design Team, leading to a redesign of the bridge in order to find alternative solutions for improving the construction.

Concerning the superstructure, carpet reinforcement hasn't been used in bridges in Sweden earlier, since rules and regulations do not allow welding of the reinforcement exposed to stress variations over 60 MPa. It is however possible to calculate where those conditions are valid and redesign the bridge allowing for partly welded, and partly clenched carpet reinforcement as well as the shear reinforcement.

LEAN CONSTRUCTION PLANNING WITH A CROSS FUNCTIONAL WORKING TEAM

Using the traditional method of constructing most often trades are subdivided into activities dedicated for formwork, reinforcement and concrete. At an optimized industrial process using different segments prefabricated and SCC, a new approach when composing the working teams for the project must be introduced. The working team on site needs to be cross functional in knowledge and experience. Hence, in the optimized production, a worker needs to be able to handle both formwork and reinforcement as well as casting of concrete. This is of course dependent on the size of the project and for this rather small bridge, the prerequisites for the workers were simply that they had to be multi-skilled.

CONSTRUCTION PROCESS AND VALUE FLOW

Important for realizing industrialization is to identify the process and even out the flow, see Figure 4, where the process has been subdivided into four main parts: foundation, plate structures, superstructure and finishing works.

To be able to utilize the benefits of the different production methods evolved from the design phase, accurate planning is essential. Therefore Last Planner ideas, (Ballard, 2000) was considered to be valuable assets and also directly applicable in the project.

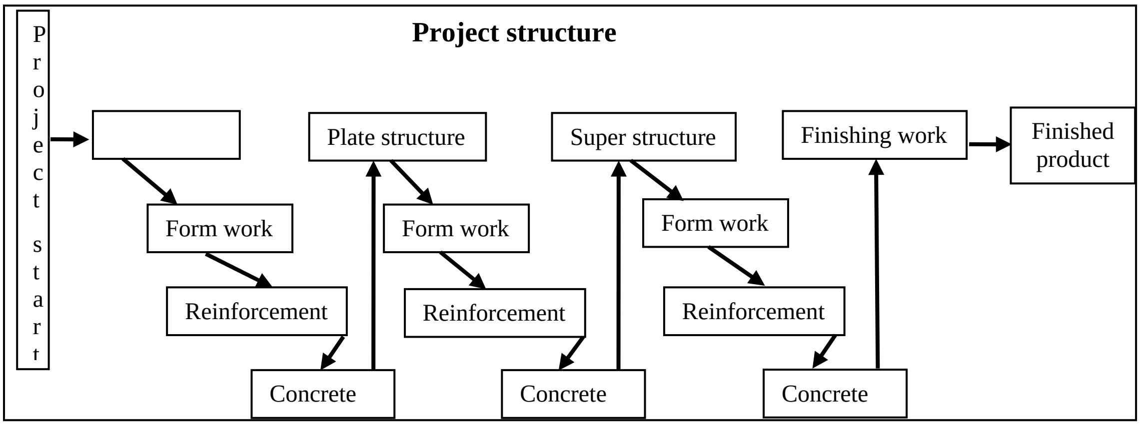


Figure 4: Project structure and activity flow scheme.

The contractor commenced construction of the full scale project in august 2006, and it was completed in November 2006 as according to the timetable. The involved number of workers shifted from 3 to 5 during the projects different stages.

As the contractor used a cross functional working team the instructions for the different working moments is of great importance. Therefore, standard operating procedure documents (SOPD) were created for everyone to use. Nakagawa (2005) suggests that SOPD is of importance for familiarizing the work in advance to the workers, for achieving the target duration and quality.

RESEARCH ACTIVITIES AT SITE

To be able to follow up the activities at site, various measurements and observations were conducted. For instance the ability of the suppliers to deliver the ordered goods on time was measured; hence the logistics of the involved parties was examined especially the prefabricated reinforcement and concrete deliveries.

Another interesting measurement in the full scale project was the productivity measurement of particular workers during a few typical working days. Every other minute short notes were taken on what the worker was doing and why, giving a more exact picture of how much time on a typical working day the worker was adding value to the product and how much of the time that was type one or type two muda. Type one muda creates no value but is necessary with current technologies and the type two muda creates no value and is immediately avoidable according to the definition by Womack and Jones (2003). The actual time and personnel usage needed for the different working moments were also examined as well as the working environment. Interviews with the workers were carried out to see if the attitude towards the different working moments changed during the project.

RESULTS AND EXPERIENCE FROM THE FULL-SCALE TEST

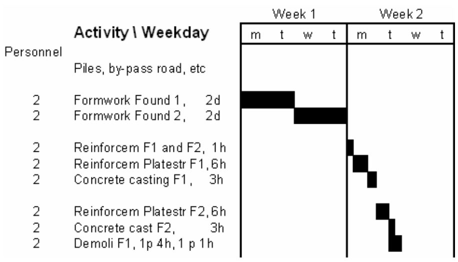
When arriving at the construction site the prefabricated reinforcement for the *foundations* were lifted and mounted directly into the formwork taking approximately one hour for both foundations together, see Figure 5a. Immediately afterwards the connecting reinforcement between the foundation and plate structure was mounted. A few hours later the same day the first foundation was ready to be cast with SCC and around lunchtime the subsequent day the second foundation was ready to be cast, see Figure 5b. All together this made it possible to save almost a week in onsite production time; see Table 2.

a)  b) 

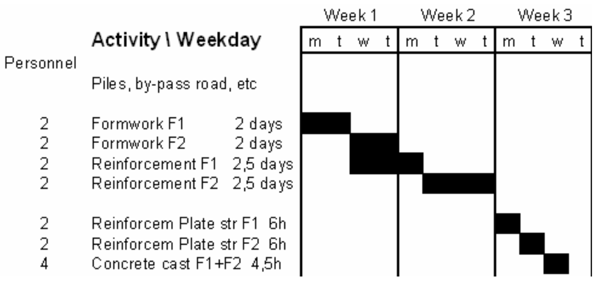
Figure 5 a and b: a) Placing the prefabricated reinforcement into the form work, and b) Casting of self compacting concrete for one of the foundations.

Table 2: Time needed for industrialization concept and traditional production for the foundations.

	Reinforcement			Concrete	
Foundation	Traditional	Industrialized		Traditional	SCC
Prodtime at site	5 days	1 hour		4,5 hours	3 hours
Craftsmen	2 persons	2 persons		4 persons	1 person
Total	80 hours	2 hours		18 hours	3 hours



a)



b)

Figure 6 a and b: Gantt charts for the foundations, a) prefabricated reinforcement and use of SCC, and b) using traditional methods.

Casting the foundations with SCC released 3 persons for 4,5 hours in total 15 man hours in comparison with the traditional casting methods, see Table 2. These persons were able to make upcoming work ready for execution.

The reinforcement for the *plate structures* was constructed traditionally on-site and SCC was used reducing the workforce with 10 man hours in total.

The *superstructure* was constructed with carpet reinforcement both in bottom and top utilizing the benefits of new design of the shear reinforcement and the higher strength concrete. This resulted in a clear productivity increase during mounting of the reinforcement at site. Table 3 demonstrates the difference in time for carpet reinforcement and traditional reinforcement. The production time at site was totally only 5 hours for three persons as compared to 2,5 days for 4 persons which is thus a considerable improvement of the industrialization.

Table 3: Time needed for industrialization concept and traditional production for the super structure. * = only reinforcement able to be changed to carpet reinforcement.

	Reinforcement*			Concrete	
Superstructure	Traditional	Industrialized		Traditional	SCC
Prodtime at site	2,5 days	5 hours		10 hours	7 hours
Craftsmen	4 persons	3 persons		4 persons	2 persons
Total	80 hours	15 hours		40 hours	14 hours

Furthermore SCC was used for the superstructure which released 2 persons and a total 26 hours, see Table 4, making it possible to divide the workers into two teams, working shift. The first team is responsible for casting the concrete and the second team is responsible for the curing. This guarantees that no tired workers are performing the curing of the concrete ensuring optimal quality of the end product. The reduction in resources needed for the concrete is 26 hours i.e. a 65% reduction in man hours and equipment usage e.g. rental costs and pumping costs in comparison to casting the concrete traditionally. Despite the large improvements on productivity achieved it seems that the degree of industrialization could be even higher. For example, during mounting of the rest of the reinforcement of the superstructure there were quite a number of wasteful activities performed. Hence the productivity study at site revealed that only 31% of the average workers day involved contributing to the finishing of the project, the rest of the time was divided into type one muda 26% and type two muda 43%, Figure 7.

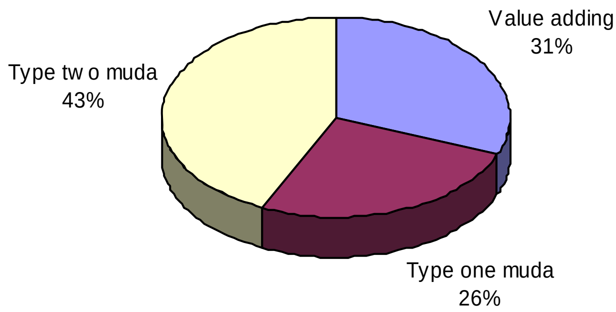


Figure 7: Productivity study superstructure for the reinforcement fixing, subdivided into direct value adding activities, type one muda and type two muda.

CONCLUSIONS

This bridge could be constructed using less resources, less materials and less construction time both in theory and in reality, e.g. for the actual bridge the production time was reduced, and the costs for construction were reduced. Moreover the bridge was constructed with a better and less stressful working environment, increased safety and less physical loads. A further discussion on working environment can be found in Simonsson and Rwamamara (2007).

The difference between the two production alternatives is typically demonstrated for the foundation and shows the importance of planning. It is clear that if construction of all structural parts of a bridge is planned and performed as shown in Figure 6 a, large reductions in production time and an increase in productivity is foreseen. To achieve these improvements it is vital to build up a confidence between involved actors to strive in the same direction. It is also important to build up knowledge on the material and processes used in the entire project. For instance, the contractor had no previous experience of SCC which led to some faults during the construction phase of the project, implying that possible benefits were not realized as anticipated.

STRUCTURAL QUALITY IMPROVEMENTS

Overall the structure quality was improved due to less rectification work during construction, better quality of the built in material. The concrete quality was increased from a traditional grade C35/45 to C50/60 giving the designer the privilege of decreasing the amount of shear reinforcement in the superstructure thus reducing difficulties when placing the reinforcement and pouring concrete. As the reinforcement of the foundations was prefabricated and shipped to the construction site, the production of prefabricated reinforcement during settled conditions with accurate manufacturing tools minimized the chance of faults occurring. This was also valid for the carpet reinforcement, especially for the top reinforcement which can be very difficult and complicated to fix and it is also associated with larger risk of injuries for the workers.

IMMEDIATE FEASIBLE WASTE AND COST REDUCTIONS

According to the productivity study, still clear waste reductions were present for the new construction approach that could be taken care of. The shear reinforcement for the superstructure did not fit in its place as it should. It was either assembled wrongly, designed with incorrect tolerances or manufactured with direct faults in the prefabrication plant. The rectification work done was pure waste i.e. of type two muda. No efforts from the contractor were made to clear up the cause of the mistake unfortunately.

Furthermore, the construction workers were uncertain of the best order to fit the reinforcement bars and some reinforcement bars had to be threaded in through holes drilled in the side of the formwork. This could thus easily be avoided if assembly instructions had been provided by the designer. In the future i.e. in the next full scale research project, a specific assembly order for the reinforcement in the superstructure is to be requested from the designer. It is also obvious that all parts involved in the project must take their responsibility to check the validity of drawings and other information before making work ready.

ECONOMY OF A LEAN CONSTRUCTION PROJECT

The main reason for hindering the inauguration of new technologies or new thinking in projects is the uncertainty of the economy in a project. There is often a short period between purchase and commencing construction, and contractors most often give a fixed price on projects and therefore have limited possibilities of altering the production and still be certain of the outcome of the economy in this short time. Hence, the possibility for new thinking is very limited.

On the other hand if there is no testing there will not be any development at all. Therefore in our research project the economy is of interest. As a summary the reinforcement showed approximately 4300€ in direct profits and a total of 78 man hours saved. Considering the economy for the concrete the benefits were negligible however the project were reduced with over 50 man hours. Indirect profits such as cost for establishment, equipment, better working environment etcetera are off course present but are difficult to estimate. Observing that this was the very first bridge construction of this type in Sweden the result is very positive!

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