Chapter 78
Tools to Prevent Waste in Material Flow in Housing Projects

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Abstract There is a lack of apartments in major Scandinavian cities. At the same time, there is a general opinion in media that the costs for housing production are too high. Studies indicate that waste, in the lean perspective, is in the range of 30–35 % of the project cost, excluding costs for land. Among initiatives for reducing waste are tools to prevent waste in material flows. This paper presents a case study in which a logistics company, a medium-sized contractor and a material supplier collaborated to develop tools for improving the material flow on the construction site. Initially, nine tools used for preventing waste in material flow is presented; logistic analysis, demand profile, process map, specifications for building hoist, delivery plan, responsibility during material handling, location in apartments, quantification of materials and control of deliveries. Then, each tool is evaluated concerning what kind of waste is reduced. Examples from a residential building project with 163 apartments are given. The costs associated with enhanced material logistics in this specific project were approximately SEK 130 per m^2, which is equal to RMB 115 per m^2. This covers the enhanced handling of 80 % of the materials. It's expected within the case project that enhanced logistics with support by the nine tools has a potential of giving a 2–5 times return on the investment. The conclusion is that material logistics requires good planning and structure in order to be effective and succeed in minimizing waste.

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78.1 Introduction

Public debates in Sweden about construction have in the past years concerned issues related to the high production costs for new buildings. At the same time, the construction industry struggles with low profit margins. Thus, there are external as well as internal reasons to reduce costs by improved efficiency.

Recent statistics show that the Swedish factor price index – which is the cost for all material, workers' wages, machines, transportation, energy and contractor expenditure constructor costs – have increased by 21.5 % for construction of new residential buildings the last 5 years. Material costs alone increased by 30.8 % [1]. The cost distribution for newly produced apartment-block houses can be seen in Table 78.1. Construction costs stands for 61 % of total production costs and last year's factor price index increase encourages construction companies to start looking for potential savings by reducing waste [2].

According to an empirical study by Josephson and Saukkoriipi [3], waste is in the size of 30–35 % of the total production cost. They argue that waste reduction should be one of the highest priorities in construction.

This paper focuses on material logistics and especially material handling. It's based on a case in which a contractor and a third part logistics company collaborate in finding ways to reduce waste by developing tools that improve material flows to the construction site and on the site. This paper is however limited to the process from the point the materials arrive to site until the materials is ready to be assembled by the workers in the apartments. The purpose of this paper is to present nine such tools and then evaluate what kinds of waste that is reduced. In this paper it is assumed that all work and resources can be coordinated by schedules and that inability to perform to schedule is rare or evidence of lack of commitment.

78.2 Material Handling and Waste in Lean Perspective

Deliveries of materials to the construction site are seldom scheduled and manufacturers and wholesale dealers report that express delivery is by far the most commonly used form of delivery when counted by number of orders [4]. Materials

Table 78.1 Cost distribution for new residential buildings [2]

Cost element	Proportion of the production cost (%)	
Value added tax	17	
Future proprietor costs, including land acquisition and municipal fees	22	
Construction cost	61	
Transport, machinery, operating expenses		12
Material		28
Wage cost – non-manual workers		5
Wage cost – craftsmen of sub-contractors		5
Wage cost – construction workers		11
Total	100	

delivery to site is a critical activity in the building process [5]. It affects productivity and needs a system for monitoring as early as possible in order to control the material flow. The supply of building materials to site without suitable planning is fraught with obstacles (Ibid). For example the need for unloading equipment interrupts other activities in production and requires storage of material, which takes space that could be used to make other production activities run more smoothly. Material handling becomes a supply bottle-neck.

Waste is often related to Toyota and the lean philosophy. Lean production, either in the construction or car industry, consists of many ideas including continuous improvement through standardization, flattened organizational structures, teamwork, elimination of waste, efficient use of resources and co-operative supply chain management [6]. The primary goal of lean production is, however, the elimination of waste [7]. Waste is generally defined as "an activity that absorbs resources but creates no value". With a construction perspective [8], define waste as "the loss of any kind of resources – materials, time (labor and equipment), and capital – produced by activities that generate direct or indirect costs but do not add value to the final product from the point of view of the client".

Vrijhoef and Koskela [9] concisely conclude three things about waste in relation to material logistics: "Firstly, even in normal situations the construction supply chain has a large quantity of waste and problems. Secondly, most of these are caused in another stage of the construction supply chain than when detected. Thirdly, waste and problems are largely caused by obsolete, myopic control of the construction supply chain". For material handling works that add value are assembly, finishing and packaging. Thus wasteful activities are those such as moving, storing, counting, sorting and scheduling [10].

Liker [7] identifies eight different waste areas from his study of Toyota: (1) overproduction, (2) waiting, (3) unnecessary transport or conveyance, (4) over processing or incorrect processing, (5) excess inventory, (6) unnecessary movement, (7) defects, and (8) unused employee creativity. Number 2, 6 and 8 are linked to work by people while the other five are linked to the flow of materials.

78.3 The Case Study: New Construction of Residential Buildings

This paper presents a case study in which a third party logistics company, a medium-sized contractor and a material supplier collaborated to develop tools for improving material logistics. For each new project they registered ideas on how the processes related to the material logistics could be improved followed by a joint meeting for deciding what improvement ideas to work on in next project. The paper focuses on the material flow on construction sites, which the logistics company and the contractor were responsible for. The case study, which concerns a new construction of residential buildings, was the third project the two companies collaborated in. One of the authors, who works for the logistics company, and the contractor's project manager were responsible for developing, implementing and evaluating the tools.

The case project was built on a turnkey contract with a public client. The site is located in Gothenburg, Sweden, at a site, which belonged to the shipping industry until the late 1970s. The project includes the construction of 163 apartments and two other facilities. The apartments are shared between four separate buildings, which range from four to eight stories each. As part of the project, a basement and parking garage will be built beneath the construction site. One of four buildings must meet the regulations for passive houses. The project includes a total of 10,111 m^2 finished gross area, excluding parking garage area, and 9,825 m^2 finished living at an estimated construction cost of SEK 173 million (RMB 150 million), excluding land acquisition and piling work. The project was initiated in March 2008 and completed in December 2011.

The study presented in this paper focuses on material handling in the frame complement phase, which was divided into four processes. The first process concerns the façade, which is a mix of plate and plaster. The second process concerns outer walls, which were built with the base materials timber, insulation and windows. The third process concerns inner walls, which were built of the basic materials timber, steel bars, insulation and gypsum boards. Bathroom walls were, however, built with gypsum boards and a board called Jackon. Ceilings, which are classified as inner walls, are built with gypsum boards. The fourth process concerns wardrobes and kitchen cabinets. These components are delivered assembled. The last three processes were chosen for the study since they cover 80 % of the materials handled on site in this phase. All assembly work was done by the contractor's own workers.

78.4 Method

Data was gathered through individual interviews and direct observations during a 2-month period. In total, 18 open-ended and semi-structured interviews were performed. The interviews were performed with individuals who had responsibility for the achievement of project targets and also worked with the chosen materials on a day-to-day basis. The interviews were held with nine individuals from the construction company: one site manager, four foremen, two worker representatives, one calculation engineer, and the CEO. Interviews were further performed with five managers at the third part building logistics company and four interviews were held with personnel from a construction material supplier. Further questions were asked in person, by e-mail or via phone. The purpose of these interviews was to get the practitioners' opinions about obstacles relating to the handling of materials.

The construction work on site was further observed during a 2-month period. Observation was undertaken as a known, non-active observer, and lasted between 1 and 3 h for each occasion and coincided with the delivery of selected materials.

A total of 20 deliveries were selected and observed arriving during the frame complement phase. The purpose of the observations was to find techniques and obstacles related to the handling of the chosen materials from site delivery until the workers are ready to assemble the material. During the observations bottle-necks that interrupted the material flow were documented. Examples of such bottle-necks are too small width of door openings, too low height between balconies, too small size of indoor elevator. Also, kitchen cabinets and wardrobes that were delivered assembled and not in packages, were larger than expected.

78.5 Example of Interruptions in a Delivery of Gypsum Board

Each material's flow on the construction site was studied, starting from the time the material arrived to the site and ending when the craftsmen assembled it. Every material's flow was interrupted of several reasons.

The following example considers a delivery of gypsum boards. Gypsum board is among the most frequently transported materials in the frame complement process. A gypsum board package is in many cases also the package, which encounters bottlenecks due to the size and weight of the package.

> *The gypsum board delivery arrived late to the site and no one was ready to guide the lorry to the correct location for being unloaded. Next, a fork lift truck was located to unload the lorry. However, after the arrival of the fork lift truck the craftsmen discovered that the temporary material store was not cleared. A new interruption occurred due to vague markings on the package which should indicate the boards' dimensions and which apartment the package should be transported to. These unclear markings created extra work since the craftsman could not guide the fork truck driver to unload the material in the right sequence for the next step, which is transportation into the house.*

The lorry was unloaded so that the material could be transported into the appropriate building (according to which apartment it goes in). The activity started with interruption because the hydraulic material transport wagon, which was used to transport the gypsum package was not correctly equipped. The wagon itself did not have distances high enough that the fork truck could take the forks away after loaded the package on the wagon.

Next time the transport was interrupted was by the building hoist. The hoist had engines, which were built in into the area used for transportation available to transport. The craftsmen needed to cut the wrapping and take away three layers so that the transport wagon with its package could fit under the engine in the building hoist. When the building hoist reached the correct level and the gypsum package was ready to be transported into the apartments, the hoist was not aligned with the door, which forced the craftsmen to scratch half of the package. Scratching could be avoided by carrying every single gypsum board by hand. Finally, inside the first door the rest of the passages were wide enough so that the hydraulic transportation wagon could be driven to the correct apartment. The passages were done wide enough in this case, since a previous logistic analysis identified that the original width was too small.

Other factors discovered that interrupted the flow of materials were weather conditions, coffee breaks, lunch breaks, height of building hoist, material garbage, blocking by other activities and craftsmen's motivation.

78.6 Tools to Prevent Waste in Material Flow

Factors that were identified as interrupting the material flow were recorded in the documents: logistic analysis, demand profile, process map, building hoist specification, delivery plan, responsibility areas, location plan in apartment for each material, quantification guide and arrival control. These are all created to ensure the correct flow of material from manufacturer to the worker's final assembly.

Logistic analysis (*1*). When the craftsmen were ready to use the gypsum board no one thought about where to put the package of boards in order to make the assembling process more efficient. The logistic analysis of construction projects is offered to construction companies on a consultancy basis by a third party logistics company. The analysis is based on internal and external material flow. The purpose of the analysis is to find critical activities that constrain the material handling. This provides internal and external transport plans, placement suggestions for tower cranes and construction elevators and production sequence (see Fig. 78.1). The process is based on a close collaboration between the consultants and the clients.

Demand profile (*2*). Each material is specified in the demand profile which has details about wrapping, packaging size, quantity etc. The contractor demands that material supplier and third party logistic companies consider the demand profile in order to avoid waste and to secure uninterrupted material handling (see Fig. 78.2).

Process map (*3*). The process map indicates how to handle material deliveries. It includes descriptions on where to unload, where to temporary store material, the route that should be used to the building hoists, where to store material if it is to be handled by crane etc. It was concluded that the deliveries should arrive between 1:00–2:00 PM and that the material should be temporarily stored at a marked position until the ordinary craftsmen finished the day at 4:00 PM. The materials were best suited to be transported to site after 4:00 PM to ensure that the transport neither interrupts nor is interrupted by work activities.

Specifications for building hoist (*4*). The building hoist specification described where the building hoist should be located and the size of the packages that will be handled. Restrictions are detailed, such as that no engine may be put inside the loading space. Weight and height demands are also specifications that need to be considered when renting a hoist. The specifications also include a checklist, which clarifies in what order work on site has to be done in advance to accomplish a successful building hoist assembly.

Delivery plan (*5*). The delivery plan describes exactly when the material deliveries take place. Craftsmen and team leaders then take the plan into account so they can

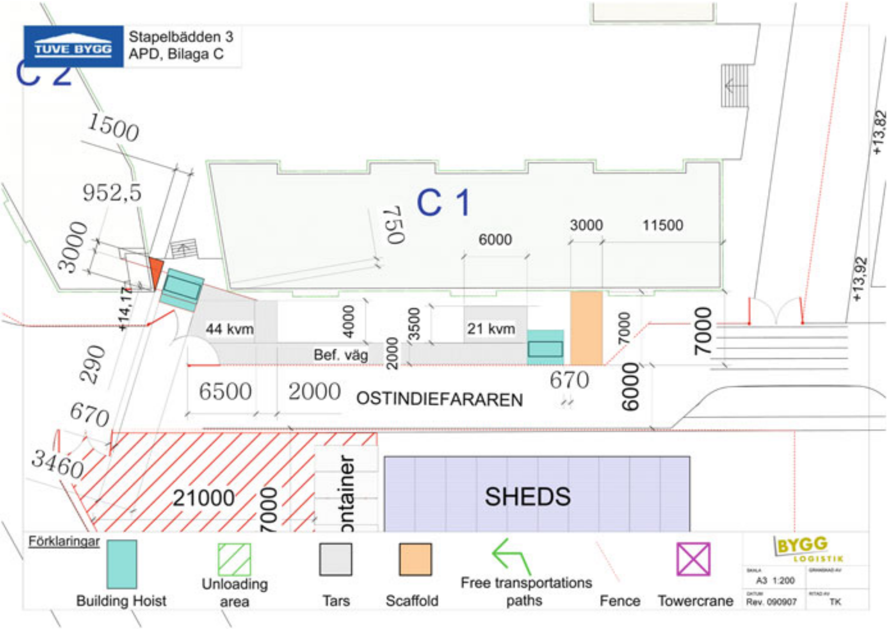

Fig. 78.1 Logistic analysis

Material	Timber
Dimension	45x195
Package curiosa	Distance under each package, not in between the bars Cut end should be oiled
Dimension package	Max Width: 900 mm Max Height: 500 mm Max Length: 3100 mm see quantification guide
Delivery time controlled	Yes between 13:00-14:00
Wrapping	Weather protected
Package quantity	See quantification guide for each apartment
Bandage	Minimum 3 pieces
Technical tool for transportation at site	Hydraulic material transportation wagon
Heap on other package	Not in apartments
Mark on package	Apartment number, Quantity
Acceptable quantity damaged	0 % Damaged, 5% Scratched
Humidity level	Maximum 18%

Fig. 78.2 Demand profile for the material timber and one of its dimensions

Delivery Number	Type of material	House	Staircase	Level	Week	Day	Time
1	Windows/Insulation /Timber	C3	C34	7-2	937	Tue,Wed	13:00-14:00
2	Windows/Insulation /Timber	C3	C33	7-2	941	Tue,Wed	13:00-14:00
3	Windows/Insulation /Timber	C3	C32	7-2	944	Tue,Wed	13:00-14:00
4	Windows/Insulation /Timber	C3	C31	7-2	947	Tue,Wed	13:00-14:00
5	Gypsum boards/steel bars/ Jackon boards	C3	C34	7-5	947	Tue	13:00-14:00
6	Gypsum boards/steel bars/ Jackon boards	C3	C34	4-2	949	Tue	13:00-14:00

Fig. 78.3 Part of delivery plan

proceed without interruptions. In a total of 52 delivery weeks, 62 delivery days were planned for the chosen materials (see Fig. 78.3). Some deliveries were delivered over 2 days because of the strict regulations from the environmental and health authority that forbids noise from machines after 8:00 PM in that area. This creates a bottle-neck that was taken into account during analysis.

Responsibility during material handling (*6*). The responsibility area document is designed to guarantee responsibility for damages that occur during handling of the materials. The project accepts no defects and a very small amount of scratches. If damage occurs, the document clearly states responsibilities for compensation and within which period of time it should be made. The document clearly stated responsibility for waste due to, for example, careless handling. One fork-lift truck driver supported the idea with the document:

> *…with clear definitions, now I know that my mistakes cost money and that I will be responsible to pay for all damages I cause. I will be more careful from now on.*

Location in apartments (*7*). A location plan is structured by demands from craftsmen and team leaders in order to secure most efficient handling of the materials but at the same time ensure healthy handling that prevents injuries. Craftsmen and team leaders asked for less carrying and unnecessary moving of material. The whole handling chain from the moment that the craftsman takes the material until he assembles it is considered. Each chosen material has its own unique spot in each apartment. Figure 78.4 shows the location for the materials used in the inner wall for apartment number 437. One of the contractor's team leaders was surprised over the effect:

> *Why haven't we thought about this before? Now we save a lot of time and make the craftsmen happier and more efficient.*

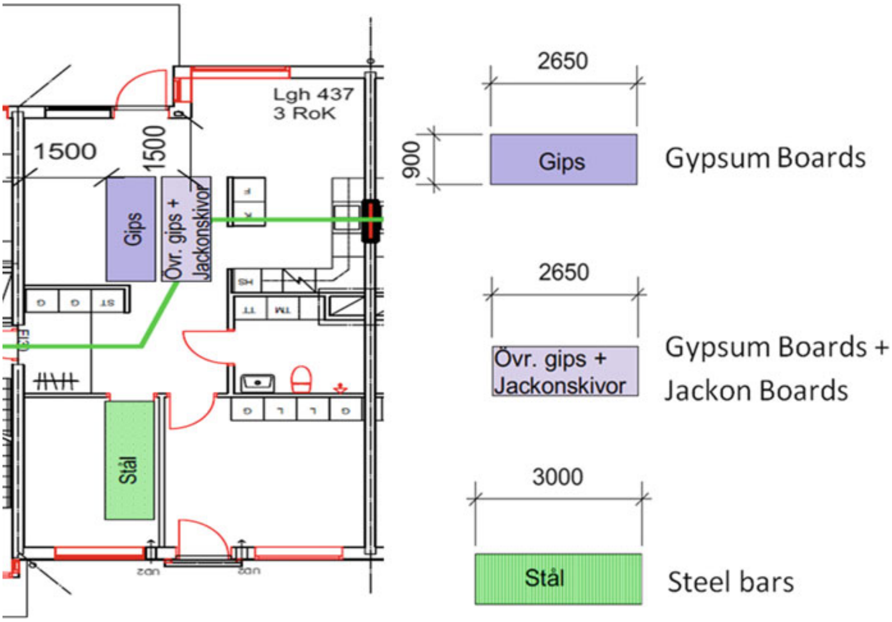

Fig. 78.4 Location plan apartment 437, inner walls material

Quantification of materials (*8*). The quantification guide shows the quantity of materials required. It is broken down to packages for each apartment. The purpose is to show those responsible for the transportation so materials are not transported needlessly, thus reducing waste. The required distributions of special steel bar systems for door opening and pre-cut gypsum boards above door openings are also taken into account in order to increase the efficiency of the craftsman. Figure 78.5 shows an example for apartment number 437 and 438.

Controlling deliveries (*9*). The arrival control is a checklist for quality controls that are supposed to be done during unloading. Each material has its own checklist points. As an example, the gypsum board controls include checking the board dimensions are correct, checking the correct quantity in both delivery and each package, checking packaging protects against bad weather and checking wrapping, defects and scratches. The controls will secure an uninterrupted material flow and no defects built in to the building.

78.7 Discussion and Conclusion

The purpose of this paper has been to present tools for reducing waste in materials handling on construction sites, i.e. from the point the materials arrive to site until the materials is ready to be assembled by the construction workers, and to evaluate

Staircase C13							
Level	**Apartment number**	**Steel bars**		**Gypsum Boards**		**Jackonboard thickness 12 mm**	
		Package quantity	Number of package	Package quantity	Number of package	Package quantity	Number of package
Level 2	**437**	32 bars	1	42 pieces	2	10 boards	1
	438	32 bars	1	42 pieces	2	10 boards	1
		Jackonboard thickness 6 mm		**Door systems and cut gypsum boards**		**Timber 45x45**	
		Package quantity	Number of package	Package quantity	Number of package	Package quantity	Number of package
		6 boards	1	6 systems	1	35 pieces	1
		6 boards	1	6 systems	1	35 pieces	1

Fig. 78.5 Quantification guide inner wall, apartment 437 and 438

Table 78.2 To what extent tools reduced various types of waste related to material handling. (*** = major influence, ** = some influence, * = minor influence, "–"= no influence)

Tool	Overproduction	Unnecessary transport	Over processing	Excess inventory	Defects
1 Logistic analysis	–	***	**	***	**
2 Demand profile	***	*	–	**	***
3 Process map	–	**	**	**	**
4 Specification for building hoist	–	***	*	**	**
5 Delivery plan	*	***	**	**	–
6 Responsibility during material handling	*	–	***	*	**
7 Location in apartments	–	***	**	*	**
8 Quantifications of material	***	*	**	*	–
9 Control of deliveries	–	*	*	**	***

what kinds of waste that is reduced by applying each of these tools. It must be noted here that it is not the tools that reduce waste, rather the appropriate use of the tools. Further, the tools have been developed in collaboration with a third party logistics company, a contractor and a material supplier.

The idea behind the tools has been to find ways to prevent all kind of interruptions in material flows. All three firms have experienced that most interruptions cause not only breaks in the flow, but also "hidden" consequences such as demotivation and needs of modifying the production plans.

In order to evaluate the tools, one of the authors used the five of Liker's [7] eight wastes that has to do with material handling on site. Based on interviews and direct observations he used a four-point scale in which three meant major influence and zero meant no influence on waste reduction, see Table 78.2. Then he found that each tool had some influence or major influence on at least two types. Further, all five types of waste were influenced by at least four of the tools. It must, however, be noted that the tools have been developed in such a way that they are aimed to work together, not as single tools.

Table 78.3 Cost for material handling, excluding parking garage (1 SEK = 0.85 RMB)

Cost item	Cost (SEK)	Cost/m^2 (SEK)
Third part logistics company	1,043,000	103
Preparing tender and selecting suppliers	222,400	22
Logistic analysis	50,000	5
Total	1,315,400	130

The case organization also experienced that the health and safety improved significantly. The work environment in the case project was considered better than in previous projects. Further, the sick-leave among managers and workers on-site was significantly lower than in previous projects. The interviews confirm that the focus on improved material handling is one reason for this improvement.

The additional activities in material handling in the case project were activities performed by the third party logistics company. Before the contractor was awarded the contract the logistics company made a logistics analysis and took active part in preparing the contractor's tender to the client. After the contractor was awarded the contract the logistics company took active part in selecting material suppliers and also transported 80 % of the material from the unloading place to the place for assemble. The majority of this transportation was done after 4 PM, i.e. after the construction work finished for the day. The cost of these additional activities corresponded to 130 SEK/m^2, see Table 78.3. The case organization perceived that the cost savings were 2–5 times higher than the investment.

The study presented in this paper indicates that there is a general lack of focus on material logistics in construction and that large costs associated with material handling are being ignored. The paper also shows that enhanced logistic capability can be achieved by early logistics planning. This helps to eliminate waste by identifying bottlenecks and restrictions to material package dimensions.

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