SUSTAINABLE INTERMODAL TRANSPORTATION OF PREFABRICATED CONSTRUCTION MATERIALS

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Non-sustainable transportation is a great part of the stress that human activities put on the environment. Transportation of construction material are today performed all but exclusively by road, a mode that is cheap and fast, but at the same time heavy on emissions. In light of this, the effects of a modal change from road to combined road/rail transportation are studied from the viewpoint of a case company producing prefabricated concrete units. The study includes economic and environmental as well as operational effects. A case study is performed at the producing company by looking at actual invoices and delivery orders for the present mode of transportations. To assess the present operations, an intermodal alternative was created and studied. The comparison clearly shows that the environmental impact of the intermodal transportation is only a fraction of that of the road transportation. However, intermodal transportation is less cost efficient, flexible and reliable. The results imply the construction industry as a whole could lessen its environmental impact by employing intermodal transportation, however, without changes in regulations and policies to negate the economic disadvantage, intermodal transportation in its current state will not be a viable option for the studied company.

Keywords: environment, greenhouse gas, intermodal transportation, prefabrication, sustainability.

INTRODUCTION

In recent decades, producing companies are striving to reduce overall costs by increasing the number of transports while reducing inventories (Groothedde et al. 2005). This makes cheap, fast and reliable transportation attractive. Road transportation currently fulfils these aspects, especially on short distances (Macharis et al. 2010). Road transportation, however, is arguably not a sustainable mode of transportation as it creates pollution, noise, accidents, congestion and wear on public road infrastructure. Pollution and emissions of greenhouse gases (GHG) are of much concern today, and, eventually, oil reserves used for fossil fuel production will become depleted.

The construction industry is responsible for large amounts of emissions due to the extraction, manufacturing and transportation of building materials, as reported by e.g. Nässen et al (2007) and Yan et al (2010); the latter claiming that 8,4 % of GHG emissions in a construction project stems from transportation (performed by road), making it the second largest contributor to emissions. From a Life-Cycle Analysis

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(LCA) perspective, Nässen et al (2007) concludes that the production phase of a building's life span is heavy on fossil fuels - partly from transportation - compared to the use phase. Since Sweden has little energy production based on fossil fuels, the share of the production phase's energy use is larger than in other countries.

Studies of the environmental impact of the construction industry often focus on material choice and the choice of employing pre-cast or conventional construction and not at all on the choice of transport mode. Yan et al (2010) mentions transport mode, however, and recommend deep-sea transportation instead of road for transporting construction materials to lessen the environmental impact of the project.

To reduce the environmental impact of the material transportation within the construction industry is an important step to reduce the overall impact of the sector. An alternative to transportation utilizing road exclusively is intermodal transportation, where two or more modes of transportation are combined. In this study road and rail are combined; the goods transported by road from the sender (an operation called drayage) to a terminal where they are unloaded from the truck and loaded onto a train (an operation called transhipment). The goods are then sent the major part of the door-to-door distance by rail and following this, the same operations are repeated in reverse order until the goods reach the destination by road (cf. Janic 2008, Dekker et al. 2009).

To address the growing need in all industries (the construction industry no exception) to reduce their environmental impact, a shift from road to intermodal transportation for a case company producing pre-cast units is considered in this study. The company is located close to Katrineholm's Logistics Centre, an intermodal terminal that makes the studied modal change a possibility. If mode of transportation is changed, costs and operational aspects - in addition to environmental impact - are important to consider. It is important that e.g. service levels and costs are not affected negatively. The purpose of this study is thus to analyse the environmental, economic and strategic consequences of a potential modal change for the company producing prefabricated concrete units, formulated into the following research question:

- What effects would changing transportation mode from road to intermodal have on 1) the environment, 2) the costs connected to the transportation and 3) the logistics operations and strategy of the factory?

The paper is structured as follows: first, a brief introduction to the field of intermodal transportation and the connections made to the construction industry is presented, together with known limitations. Following this, the method, the reference scenario and its intermodal counterpart are described. The last two chapters contain a comparing analysis of the two scenarios and a concluding discussion.

INTERMODAL TRANSPORTATION AND THE CONSTRUCTION INDUSTRY

Pollution and other environmental issues that arise from transportation, such as noise, congestion and accidents, are they very urgent problems today, especially in the light of global warming (Forkenbrock 2001). Greenhouse gases (GHG) are a group of gases including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), carbon tetrafluoride (CF4), sulphur hexafluoride (SF6) and hexafluoroethane (C2F6). Carbon dioxide (CO2) is the GHG with largest climate impact, together with methane and nitrous oxide. Intermodal transportation often has less environmentally impact than their road counterpart, mainly due to the reduced use of trucks; however, they can be more or less GHG efficient in themselves. The source of electricity used to propel locomotives has great impact on the level of environmental impact for transportation that involve rail (International Energy Agency 2012). In Sweden, 41 % of the electrical energy is generated by hydroelectric power plants, while 36 % originates from nuclear power plants, 10 % from thermal power and 4 % from wind power. Just below 8 % of the energy is imported from (possibly) less environmentally friendly sources (Swedish Energy Agency and Statistics Sweden 2012). Specifically, that means that 77 % of Sweden's produced energy generates no or close to no CO2 per kWh (International Energy Agency 2012; Lenzen 2008). However, since Sweden as part of Europe is part of a greater electrical network, there are difficulties to determine the actual source of the electricity. When Sweden's own production is maxed out, electricity has to be imported. Therefore, any extra electricity used, the marginal electricity, can be assumed to come from the least environmentally friendly source Europe can mobilise. To take this into account, several different sources of the electric energy has been considered, and specifically how much CO2 per kWh is emitted from each source. As can be seen in Table 1, hydroelectric and nuclear power is at the bottom of the list, while coal is, by far, the least environmentally friendly source.

Table 1: Emission factors for different electricity producing technologies. Truck diesel added for comparison (International Energy Agency 2012 except diesel: EcoTransit 2011).

Energy source	Coal (OECD max, 2010)	Coal (Sweden, 2010)	Oil (Sweden, 2010)	Gas (Sweden, 2010)	Average (Sweden, 2010)	Hydro-electricity & nuclear	Diesel
CO2/kWh (grams)	1230	796	385	209	30	0	230

Combustion of diesel is among the more environmentally friendly alternatives when it comes to GHG intensity. How then, can intermodal transportation be considered better for the environment than diesel propelled road transportation? The answer lies in the energy efficiency, as will be evident below.

Road transportation is often favoured over intermodal rail freight for several reasons. Delivery time is an important aspect of many transports and road haulage is usually faster on short distances since intermodal transportation involves possible waiting time and transhipment at the terminal in addition to the actual movement of the goods (Janic 2008). Connected to this is the delivery time reliability. Since passenger trains are commonly given priority over freight trains on shared infrastructure, a delay anywhere on the connection can cause a significant delay to the intermodal transportation (Törnquist and Persson 2007). Because of time tables, the flexibility of the transportation is reduced since a train cannot be made to wait for a delayed drayage or interruption in production. A certain resistance against intermodal transportation can also be detected among shippers (Patterson et al. 2008). Should a road alternative and an intermodal alternative be all but equal in every aspect, some shippers tend to favour the road alternative, mostly because of prejudices and lack of knowledge regarding intermodal transportation. The cost is a very important aspect of different modes of transportation's competitiveness. Currently, road transportation is a very cost effective mode of transportation and intermodal alternatives are having a hard time being competitive (Janic 2008). In addition, if road transportation costs rise, so does the cost for intermodal transportation since trucks are involved in the drayage part of intermodal transportation. The length of the drayage operations also have a large impact on the distance where intermodal transportation become preferable to road transportation, called break even distance. The actual break even distance depends on a large number of conditions, aside from drayage length, and can be anywhere between 90 km and 1050 km under certain conditions (Dekker et al. 2009; Janic 2008; Macharis et al. 2010;).

Other consequences of transportation in general are accidents and congestion. The drayage part of intermodal transportation has the same accident rate as the total road freight transportation of the same category (Janic 2008). Congestion, mostly referred to road traffic, can also occur on rail links, where a slow moving freight train or a delayed train can cause congestion on the confined infrastructure.

Construction sites in crowded metropolitan areas often suffer from congestion-like situations on the actual construction area (Jaillon and Poon 2008) and the planning of logistic activities connected to a construction project can be substandard (Said and El-Rayes 2011). Among these activities is the planning of storage areas, material arrival times, presence of heavy machinery at the right time, cranes capable of lifting the required weight for unloading, etc. These factors may in turn impact schedules for transports bound for the construction site. It is therefore important that building material arrive to the construction site loaded in a way that makes insertion into the construction object easy. The delivery precision can be increased by employing the receiving terminal area as temporary storage for the units, as in the case of ‘floating stocks’ (Dekker et al. 2009, Pourakbar 2009). Thus material for several days’ construction can be stored at the terminal and hauled to the construction site as the demand is realised. This would shorten lead times, increase both delivery reliability and flexibility and reduce on-site storage levels. Cole (1999) reports that construction-related GHG emissions are lower when prefabricated concrete units are used instead of cast-in-place. Instead, transportation of material and workers is the largest portion of the emissions for a construction project. Quale et al (2012) reports similar results and show that on average, conventional construction emitted 40 % more GHG than modular construction, even though material for prefabricated construction units needs to be shipped first to the production facility and then to the construction site. Newer buildings are also, once in use, often energy efficient: for a building with optimal energy efficiency, the material production and construction is responsible for 60 % of the energy use of the building from a life cycle perspective (Quale et al 2012).

Many factors that influence the modal choice for a specific transportation are political in their nature and indeed, the European Committee works to induce a modal shift away from road transportation towards more sustainable transportation modes such as rail, inland and short sea shipping (European Committee 2009). Sustainable involves three aspects: environment, economy and society. In this study, the environmental aspect considered is CO2 emissions, the economic aspects are transportation- and overhead costs (such as increased inventory, delays or operational changes) depending on the selected transportation mode. The societal aspect is not considered here, but instead the strategic aspects of a modal change for the company. Similarly, political aspects such as fuel taxes, kilometre taxes, fees for using less environmentally friendly engines or subsidisations for using sustainable modes are, though of great interest for intermodal transportation in general, not included in this study. Instead, the current rules and regulations are assumed to be kept in place, making this study a worst case scenario for the competitiveness of intermodal transportation. Likewise CO2 are the

GHG most commonly referred to regarding environmental impact; thus, CO_2 is the only GHG that is considered specifically in this study, while other kinds of negative effects on the environment (e.g. NO_x, SO_x, particles, noise etc.) are not.

METHOD

The case study is performed at a Swedish construction company that has specialized in prefabricating concrete units, Prefabricated Concrete Units Company (abbreviated PCUC). In an earlier paper, the same company's delivery regions were analysed to find if any were suited for intermodal transportation instead of road transportation (Persson et al. 2011). The city of Gothenburg is located in western Sweden and was deemed not eligible for intermodal transportation in the earlier study. However, the data in the previous study was accumulated over entire regions, meaning that individual projects within a region could possibly be favourable for a modal change none the less. Therefore, a specific project - started in 2009 and ended in 2010 - which PCUC performed deliveries to, suitable in scope and with data readily available, was selected for further study. While a single case might not give fully generalizable conclusions, it can still be used to falsify propositions. Deliveries were performed by road transportation exclusively. Data on the transports, including costs, measurements, weight and number of load carriers were obtained from invoices and delivery notes collected on several visits to PCUC's production plant during the case study.

To calculate CO_2 emissions, an online tool called EcoTransit (EcoTransit 2011) was used. As an online tool available to the public, EcoTransit functions such that the starting and end points of the transportation are entered, along with transportation mode (road, rail or intermodal), type of truck (if applicable), transported weight, and handling (if terminals are involved). It then calculates the energy consumption of hauling the cargo from the start to end points. There is, of course, a margin of error in calculations of this type; however, the larger picture regarding emissions is of interest in this study. Therefore, EcoTransit is believed to be accurate enough. In addition, calculations for both scenarios are performed in the same way, arguably making them comparable. There are a number of similar tools to be found online and EcoTransit was specifically selected because of availability and reliability (cf. Fridell et al 2011). To analyse an alternative intermodal transportation, an intermodal scenario was created, where, again, EcoTransit was used to calculate CO_2 emissions from drayage, transhipment and rail haul. Once the energy consumed by the transportation (in kWh) was calculated, the amount of CO_2 released from the transportation was determined. Costs for drayage and transhipment were collected from companies performing these activities today and recalculated to prices of 2009. The cost of the rail haul depends on numerous factors, including: distance, train length, available space, additional freight on the train, and finally, perhaps most important of all; the specific deal, i.e. competition pricing, between the producing company and the rail operator (Button, 2010). Here, only the distance and train length are known and therefore it is possible to provide an estimate of the size of the rail haul costs - provided that the transportation is to remain economically favourable compared to the reference scenario - as shown in equation (1) and (2) below. Let C_{im} denote the total cost for the intermodal transport, C_d the drayage cost, C_t the transhipment cost, C_{rh} the rail haul cost and finally C_r the cost for the reference scenario.

$$C_{im} = C_d + C_t + C_{rh} \quad (1)$$

$$C_{im} \leq C_r \rightarrow C_{rh} \leq C_r - (C_d + C_t) \quad (2)$$

REFERENCE SCENARIO

PCUC produces the concrete units on an assembly line. Once complete, the units are stored temporarily in the factory for a few hours to a few days. The loading order for the units is determined by the contractor and the units are loaded onto load carriers by fork lift. The load carriers, which share measurements with a common 20-foot container, are then loaded onto a truck that hauls them directly to the construction site where they are unloaded directly into their correct placement in the building. Sometimes several trucks leave for the same destination on the same day. Load carriers are then returned as soon as the trucking company has an unloaded vehicle bound for a destination close to PCUC's production plant. The transported distance from PCUC's production plant to the construction site is 330 kilometres. The number of transports per day range from zero to four, according to the needs of the contractor. The 146 deliveries that were made to the specific site were performed on 87 unique dates. Out of these, 38 had a single transport leave PCUC's production plant bound for Gothenburg, 42 had two transports, 4 had three and 3 dates had four transports. Of the 38 dates that only had a single transport, eight also had a single transport the following day. These numbers suggest that grouping of certain transports on a train should not be a problem for either PCUC or the contractor.

The trucks can carry up to 40 tonnes, depending on the shaping of the specific units. The stipulated weight per transport is 33 tonnes, i.e., the transport company charges for 33 tonnes even if the actual weight is less, and for the actual weight, should it exceed 33 tonnes. Hence it is profitable to load the transports as efficient as possible. Even so, 68 % of the transports are loaded with less than 33 tonnes. 16 % of the transports are loaded with less than 20 tonnes. Many of these transports occur on the same day as other transports, indicating that these less-than-20-tonnes transports are used to fill up the demand that did not fit onto the other transports of the day. A fuel charge is added to the transport cost, and should additional waiting time be incurred in the loading or unloading processes, a fee of roughly twice the ton cost is charged per hour waited.

INTERMODAL SCENARIO

The intermodal scenario was created with the goal to have no negative difference for the construction site in terms of service levels. The prefabricated units are assumed to be transported on a standard intermodal wagon, called Sgs, with a wagon weight of 22.5 tonnes, maximum payload of 57.5 tonnes and loading area length of 19.5 meters (Green Cargo 2013). When disposing a freight train, instead of several unique road deliveries performed on the same date, all of a specific day's (or perhaps several days') deliveries would be grouped and hauled on the same day. However, the ability to do so is depending on a number of factors, among which are: (1) production capacity at the producing facility, (2) in the case of several day's deliveries grouped on a single transport, some sort of (temporary) holding area at the receiving terminal and (3) the construction site must not be negatively affected by the change. In the intermodal scenario, all deliveries performed on the same day in the reference scenario are assumed to be grouped onto the same train, which presents no problem for points (1) and (3) and makes (2) void. Train capacity is assumed to always be available. The cargo for each transport was, in a spread sheet, "loaded" onto railcars so that neither length- nor weight limits were exceeded. A fully loaded Sgs railcar has clearance for the entire rail haul distance - 321 km - between the two cities in the study. A medium length train of 1 000 tonnes (EcoTransit, 2011), with a load factor of 70 %, was used.

The same type of truck as employed in the reference scenario was selected for the drayage operations. Persson et al (2011) considers additional types of truck; however, the other types require additional investments from one or more parts in the transportation chain and are therefore not considered in this study. The distance from PCUC's production site to the terminal is 4.5 km, and from the receiving terminal in Gothenburg the distance to the construction project is 1 km. Despite the short distances, a contact on a Swedish shipping company estimated three hours per drayage operation. Drayage costs are, according to the logistic centre, charged by the hour, where the minimum charge is two hours. To accommodate for uncertainties in the drayage time, two alternatives are considered, where drayage can be completed in 4h for each transport (2h at each end), or 6h (3h at each end). Drayage costs are also subject to e.g. the deal between the customer and the shipper. The number of drayage operations is assumed to be the same as the required number of transports in the reference scenario. Transhipment is performed by a reach stacker at the terminal and charged per movement; the cost depending on e.g. the weight of the goods and, again, the specific deal closed with the terminal. A reach stacker often has a capacity above 40 tonnes and can lift entire containers and trailers, which implies that the weight of the load carrier is not limiting.

RESULTS AND ANALYSIS

Using EcoTransit, the total amount of kWh consumed was calculated. The reference scenario consumes 352 000 kWh, compared to 42 000 kWh for the intermodal scenario. The intermodal scenario is thus more efficient since it requires only 12 % of the amount of kWh needed to transport the units by road. Combining these numbers with Table 1 shows that the reference scenario, employing diesel powered Euro V-trucks, emits a total of 81 100 kg CO2, assuming 0.23kg CO2 per kWh (EcoTransit 2011). Depending on the electrical technology utilized, the intermodal scenario emits different amounts of CO2, as summarized in Table 2. It is obvious that even with the least environmentally friendly source of electricity employed within the OECD the intermodal alternative emits less than half of what the reference scenario does.

Table 2: CO2 emitted (in kilograms) per energy source. The road row includes transhipment.

		Intermodal scenarios				
Energy source	Reference scenario	Coal, OECD max	Coal, Sweden	Oil, Sweden	Gas, Sweden	Hydro / nuclear
Rail (electricity)	-	36 900	23 900	11 600	6 300	0
Road (diesel)	81 000	2 700	2 700	2 700	2 700	2 700
Total	81 000	39 700	26 600	14 300	9000	2 700
Difference	0 %	-51 %	-67 %	-82 %	-89 %	-97 %

The total cost of the reference scenario is set to 100 monetary units, which includes the actual transportation of the units, wait time costs and fuel addition. The costs for the intermodal scenario are divided into three distinct parts: drayage (by road), transhipment (by reach stacker) and the actual rail haul. The drayage and transhipment costs can be considered to be static. The total transhipment cost for the project is either 10.4 or 20.2 % of the cost of the reference scenario, thus creating a best and a worst case scenario. Together with the two alternatives for drayage times, four alternatives are created and the drayage and transhipments costs (expressed as a percentage of reference scenario costs), as well as the implications for the cost of the rail haul, are summarized in Table 3.

Table 3: Costs, given as a percentage of the reference scenario, for the different transhipment and drayage cases.

Case	Transhipment cost	Drayage cost	Total	Rail haul max cost
Best / 4h drayage:	10.4	63.3	73.7	26.3
Best / 6h drayage:	10.4	94.9	105.3	-5.3
Worst / 4h drayage:	20.2	63.3	83.5	16.5
Worst / 6h drayage:	20.2	94.9	115.1	-15.1

DISCUSSION

Using equation (2), the results shown in Table 3 implicates that the cost of the rail haul should not exceed, in the best case scenario with 4h drayage, 26.3 % of the reference scenario. This translates to 82 SEK per tonne, roughly equal to 10 €. In the worst case scenario with 4h drayage, the corresponding number is 52 SEK or a mere 6 € per tonne. To put these prices in perspective, the cost for an optimally loaded truck (33t) in the reference scenario is 250 SEK or 30 € per tonne. With 6h drayage the intermodal scenario is more expensive even before the cost of the actual rail haul is considered. The cost of the rail part of the intermodal transportation is hard to estimate since rail transportation is underutilised in Sweden, and prices stated from transportation service providers in the rail sector might not be accurate due to competition pricing.

An overall environmentally friendly image - where transportation is an integral part - might well win an order from a construction project that focuses on reducing their environmental footprint. Such a project is likely to choose pre-cast concrete (Quale et al 2012). For PCUC, having streamlined the production process regarding emissions and waste, the next thing to turn to would be the transportation. Using intermodal transportation, PCUC can, in this case, considerably lower their transportations' CO_2 emissions. The amount of kWh consumed by the drayage part of the transportation is roughly 18 % of the kWh consumed by the entire transport. As the drayage distance increases, this percentage increases. For a train powered by coal-generated electricity, the environmental break even drayage distance is 160 km, or 30 times the drayage distance of this specific project, indicating that the short drayage distances in this study is not the sole contributing factor to the low environmental impact.

Besides economic and environmental effects, there are other effects of a modal change; the flexibility of both the transportation and production facility will decrease, since rail transportation is inherently less flexible than road transportation. The risk of delayed transports increases by using rail transportation since it is more vulnerable to infrastructure disturbances. A small delay in production may also cause a delivery to arrive hours if not an entire day late, something that can put the whole construction site at a standstill. To lessen this risk, PCUC can still employ road transportation to act as a backup system. This could also be put to use to cope with near-time changes in the requested deliveries, but would undoubtedly increase costs for PCUC. Risks connected to the transportation mode of choice and how to counteract them must be studied in depth by the company in the light of a modal change. One way of lessening the negative impacts regarding flexibility and delivery time - as well as the risk of delays - would be to employ the floating stock practice as Dekker et al (2009) and Pourakbar (2009) describes; that is, the prefabricated units could be shipped from the factory a few days in advance and stored at the receiving terminal to be called from there by the construction site. Both flexibility and lead time would increase compared to the present practice. This would, however, increase costs since storage area must be rented, as well as require the receiving terminal to have the necessary storage capacity and the long-time planning from the construction project to be even more accurate.

A company considering a modal change must also consider whether the selected mode of transportation is suitable for the business and the products. The choice of transportation mode needs to support the way in which the products compete on the market. Products that compete with short lead times need a supply chain that provides short lead times, while products that compete with low costs (low prices) needs a supply chain that is very cost efficient. The intermodal transportation in this particular case is less flexible, more expensive, and takes longer time than the road alternative. The only positive effect is the lesser environmental impact due to lower emissions of CO2. Should PCUC employ intermodal transportation they would probably not still be able to compete on the market, since as of today, no construction company sell their products exclusively due to low environmental impact.

CONCLUSIONS

The construction industry would benefit, from an environmental point of view, by employing intermodal transportation instead of conventional road transportation. The effects of a modal change on 1) the environment, 2) the costs connected to the transportation and 3) the logistics operations and strategy of the factory, were examined with the following results. 1) Depending on the energy source used to propel trains, GHG emissions from transportation of pre-cast concrete units can be lowered with at least 51 % and possibly as much as 97 %. 2) Intermodal transportation are however more expensive than road transportation and would reduce flexibility, reliability and delivery speed, which in turn may increase costs further. 3) New threats are introduced, such as risks of delays, changes in production schedules and that intermodal transportation do not necessarily support the market strategy of the company. It is obvious that a modal change would not be beneficial for PCUC, despite the environmental advantages. From this case it can be concluded that intermodal transportation in similar settings has a hard time being economically competitive compared to road transportation over comparatively short distances. More generally, it is also clear that intermodal transportation do not favour deliveries that are time or delay sensitive; however, the environmental benefits for the construction industry are undeniable. To become competitive, operations that make up intermodal transportation need to be optimized in terms of precision, time and costs, the latter possibly remedied by regulations and policies. These are areas for future work, in addition a survey about the attitude towards intermodal transportation among companies in the proximity of the logistics centre.

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