The transport footprint of Swedish construction sites

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The transport footprint of Swedish construction sites

Ahmet Anil Sezer and Anna Fredriksson

Department of Science and Technology, Linköping University, SE-601 74, Norrköping, Sweden

Corresponding author: ahmet.sezer@liu.se

Abstract. Earlier studies related to GHG emissions from the construction industry are focusing mainly on impact from the phases of building use and on-site production while neglecting the footprint due to transportation during the production phase. In this paper the aim is to investigate transport footprint owing to material and waste transports to and from construction sites in Sweden, based on secondary data analysis of construction projects. The choice between efficient logistics considering the time pressure in construction projects and logistics with reduced GHG emissions is a difficult one, however previous studies report that with better logistics solutions and planning, both goals can be achieved. This study contributes by delivering a better understanding of the transport patterns of construction projects as well as the GHG emissions from construction transport. Among the studied projects, 2450 transports/project and 31 transports/flat are noted. Transport footprint from the new flat production at 2017 in Sweden is estimated around 422800 tons CO₂. Increasing the understanding of the transport patterns will lead to better policies to control traffic and better use of construction logistics setups for different phases of projects. Since the main limitation here is data quality and lack of data, further research aims to improve data collection, investigating possible data sources and their quality.

1. Introduction

Urban construction is heavily dependent on logistics activities [1]; as much as 60–80% of the gross work involves materials and services purchased from suppliers and subcontractors [2]. Products (i.e. buildings) are physically big and immobile and are produced at the site of use [3], and therefore generating a great number of transports to ensure materials and resources at the right amount and right time available on the construction site [4, 5]. However, the logistics activities related to construction, if not managed appropriately, become a source of significant environmental harm [5]. Transports to the construction sites are included in the stage A4 of the European standards for Life Cycle Assessment and the Swedish Boverket will consider the stages of A1-A5 in their climate declarations of buildings which will be enforced in 2022. Still, today we lack detailed understanding of the traffic impact of construction and thereby the greenhouse gas emissions linked to these transports.

Earlier studies estimate that the construction traffic compose 20% (ton km) of the goods traffic in Sweden [6] and 6-8% of GHG emissions in construction projects are due to transportation of materials [7]. Environmental impacts of materials and machinery deliveries to construction sites as well as waste from construction sites are often neglected. There are no demands, at least in Sweden, on measuring the transport GHG emissions of construction projects owing to the lack of knowledge of how to capture this impact, i.e. what data do we need to describe the traffic pattern of a construction project, who owns the data and how the data quality is. Therefore, in this paper the aim is to investigate transport footprint owing to material and waste transports to and from construction sites in Sweden,
based on secondary data analysis of construction projects. By having a clear picture of number of transports due to construction projects, improvements can be made to increase safety and comfort of citizens (contributing to SDG11 – making cities and human settlements inclusive, safe, resilient and sustainable), increase efficiency of transportation in cities and for construction projects (contributing to SDG9 – building resilient infrastructure, promoting inclusive and sustainable industrialization and fostering innovation) and reducing GHG emissions due to road freight transportation (contributing to SDG13 – taking urgent action to combat climate change and its impacts).

The paper is organised as follows. First earlier studies of GHG emission calculations in construction and how to calculate traffic impact are presented. Second the research process of data collection and validation is discussed and third the results from analysis of the collected data are introduced. Fourth and finally, conclusions are drawn.

2. Earlier studies
A construction site has three major transport flows: material, equipment and labour. These flows require transports to and from construction sites, for example materials leaving manufacturers’ warehouse, transportation to construction sites, unloading and storing at construction sites, ending when the materials leaving storage area [8, 9]. The material flow also generates a waste flow and transportation of excavated materials which is a part of waste flow, represent the largest proportion of the transports in a construction project [1]. The construction process is composed of various construction activities generating GHG emissions [8, 9]. Yan, Shen, Fan, Wang and Zhang [7] identify six sources where GHG emissions in building construction come from: manufacturing of building materials, transportation of building materials, transportation of construction equipment, energy consumption of construction equipment, transportation of workers and disposal of construction waste. Whether to include material production and transportation as a construction process is an important dilemma [9] considering that in construction projects, average GHG emissions of 67%, 19% and 14% come from materials, equipment and transportation [10]. Major GHG emissions are carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4) while carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM) are classified as non-greenhouse gas emissions. Carbon emissions build up to 82% of total GHG emissions [11].

In order to calculate GHG emissions due to transportation, two different approaches are used, energy based or activity based. Yan, Shen, Fan, Wang and Zhang [7] rely on total amount of building materials (ton), total distance of transportation for building materials by land (km), GHG emission factor for transportation by land (kgCO2-e/ton km)/1000. Sandanayake, Zhang and Setunge [10] calculate emissions by using quantity of fuel type (kJ), the energy content factor for fuel type (Gj/KL), CO2 emission factor for the fuel type in kgCO2-eq/Gj/1000. They calculate non-greenhouse gas emissions by using vehicle kms travelled and exhaust emission factor. Their transport data relies on distance from the distribution plant to the construction site which is determined by calculating road map distance between two destinations and cumulative kms travelled by the vehicle which is obtained from the vehicle driver. Gan, Cheng, Lo and Chan [12] refer to gate-to-site carbon emissions which is based on total transportation distance for a material (km), energy consumption indicator of vehicle for transporting the material (litre/km), carbon emission factor of fuel and gross floor area of the building. Vehicle movements, i.e. no of transport and distance, is not only useful while calculating GHG emissions of transportation, but also a suitable key performance indicator for measuring logistics performance of construction projects [13].

Estimating transport GHG emissions require data on five transport performance indicators: (1) number of transports, (2), vehicles used for these transports, (3) transported volumes of materials and resources, (4) vehicle-kilometres and (5) tonne-kilometres. However, collecting such data is difficult owing to the fragmented supply chains in the construction industry with a large number of actors involved such as developer, main contractor, subcontractor, suppliers, retailers, building merchants, transport providers [1, 14]. Data are often scattered among these actors which makes it time consuming to collect considering that the first step is to identify which actor is the customer of a transport and what is transported. Next, for the same transport, details need be obtained including
which supplier carried out the delivery and from where. In an industry where track of deliveries are not kept digitally, data collection becomes difficult. Thus, the few earlier studies calculating GHG emissions for construction projects have been of rather small projects focusing on LCA of a single or few case studies (e.g. two case studies to demonstrate results of GHG emissions from construction phase [15] and comparing emissions at foundation construction by relying on two case studies [10]). In order to capture the transport impact of construction traffic in a city or a country and to forecast future transport impact of construction traffic, we need to find data which will enable us to estimate traffic due to a new project.

Within the traffic research, earlier models to estimate and predict transport demand are based on some type of gravitation model [16] combined with knowledge of land use, inhabitant data and travel demand surveys [17]. However, none of these specifically focus on the traffic generated by construction projects.

3. Research process

The research process in this paper was based on three phases: (1) how to collect construction transport data on a large scale, (2) how to validate the quality of transport data and (3) how to use the collected data for calculation of GHG emissions. How each of these phases were carried out is elaborated below.

As previously mentioned, the data required for each project is (1) number of transports, (2) vehicles used for these transports, (3) transported volumes of materials and resources, (4) vehicle-kilometres and (5) tonne-kilometres. The goal was to collect data for all types of transports entering and leaving construction sites, i.e. material, equipment/tools and personnel. However, personnel transports have not been the focus of this paper and are not further considered here. With data, the aim was not only to calculate GHG emissions, but also to create transport patterns for different types of projects and phases of the projects in order to forecast transport impact for future projects. Therefore, a data collection guide was developed, see Table 1. The intention was to have several projects for each part of Table 1 and to combine data instead of collecting data of all types of transports for a single project. In order to forecast transportation impact for future projects, data including project size, time frames and type of project were also collected.

| Table 1. Data collection guide |
|-----------------------------|
| **Excavation** | **Groundworks** | **Frame stage** | **Completion** |
| Waste | Project 1 | Project 3 | Project n |
| Materials | Project 2 | | |
| Tools | | | |
| Machinery | | | |
| Personnel | | | |

To collect data, we started with organisations where we knew transport data from various projects were stored digitally. Thus, in line with Lacoste and Johnsen [18] we have used ‘tacit knowledge’ gained through longitudinal immersion in the field [19] to guide the selection of illustrative cases in Sweden, see result section below for presentation of data included in this paper. This type of data can be found as part of construction logistics setups (CLSSs) such as checkpoints [3, 20] or construction consolidation centres (CCCs) [1, 13]. These setups gather data with the help of either or both booking calendars and sensors at the gates, which means these setups track the transport flow to and from sites. Usually the demand to gather such data comes from municipalities and developers who are responsible of maintaining accessibility and mobility [21, 22]. The data in this paper come from both gates and calendars. Data from calendars are based on construction companies booking a time (which varies depending on what is delivered) for their upcoming delivery. Companies also book equipment required for unloading deliveries. Data from gates is collected via some counting device at the gate, ticking each time a truck pass. In the best of the worlds, the device can categorise vehicles as heavy or light based on
their length. The gates can also be equipped with cameras capturing the license plates of trucks which allows trucks to be identified and classified. Moreover, based on the pin code entered when entering the gate, trucks are connected to specific projects.

In total, twenty potential cases in Sweden were identified for data collection. Getting access to data has been a slow progress, therefore, the data in this paper came from two cases, one in Stockholm and one in Uppsala. Data came from (i) twelve projects in Stockholm between January 2014 and December 2017, (ii) the same neighborhood of Stockholm between February and November 2019 and (iii) another neighborhood in Uppsala between March and November 2019 where twelve construction projects are on-going.

Poor data quality has been an issue during data collection which can have severe impacts [23]. Data quality can be measured relying on several dimensions including accessibility, completeness, ease-of-manipulation, error-free and interpretability [24]. When assessing data quality, it is important to separate task-independent and task-dependent assessments, where task-dependent assessments include knowledge about the application context [24]. When assessing data for CLSs, it is important to be aware of rules which have been set for booking. In the context of CLSs it is important to separate data from booking calendars and gates. Booking calendars only contain material and machinery deliveries and there is a low rule adherence, in some projects only about 50% of the deliveries are booked. Moreover, whole day tasks such as transport of excavated materials or concrete are often not booked as single deliveries, instead they are booked as full days. Thus, it is impossible to tell the exact number of transports. Data from gates usually have a higher quality since they register all entrances and exits of the area. However, tail gating is a problem which can count for around 5% of the transports. Furthermore, even though some gates use personal codes, these codes can be shared with others which generates difficulties of connecting a transport to a specific delivery. In some cases the gates are also shared by several projects which means transports can enter using one project code while delivering to several projects within the area. Despite these drawbacks, data quality at the gates are still a much better source compared to the booking calendars.

Another issue with the collected data is that we are still missing data on (3) transported volumes of materials and resources (this could perhaps in some cases be retrieved from booking calendars or purchasing orders), (4) vehicle-kilometres and (5) tonne-kilometres. The last two types of data should be obtained from another source, in order to know where the quarries and waste depots are located and who the major suppliers are. The plan for future research is to gather this data from transporters or suppliers. However, this requires some easy way of connecting the delivery and the transport. Thus, OD-matrixes of the construction site will not be captured. It is important to note here that according to Akintoye [25] some suppliers have continuous deliveries to construction sites, and some have fewer deliveries during a project. For us it is interesting to capture the main flows, i.e. the ones coming many times or the ones coming a long way. Even though the lack of data and low quality, based on the data we have today, it is still possible to start identifying the transport patterns of construction sites.

4. Results

4.1. Twelve construction projects (2014-2017 period)

The projects and information including their start and finish times as well as number of transports are presented in Table 2. The CO₂ emissions are calculated by using an average emission factor for road transports, 62g CO₂/ton-km. The average values for 2017 were used in the calculation, (i) average weight carried by Swedish trucks is 16.4 tons and (ii) the average distance driven by Swedish trucks is 92 kms [26]. It is worth noting that a large proportion of construction transports are due to excavation works which means construction trucks are expected to carry more tons while travel less distances than the average numbers provided above. In average of 2450 transports/project and 31 transports/flat are carried out, however as it can be seen in Table 2, there is a large variation between projects which might to some extent be due to low data quality.
Table 2. Details of twelve construction projects from Stockholm

| Project | Gross area (m²) | Size | Time | Transports | Transports/m² | Transports/flat | CO₂ emissions (tonsCO₂) |
|---------|----------------|------|------|------------|---------------|----------------|------------------------|
| A       | 21458          | 158 flats | 2014-2017 | 961            | 0,05            | 6,1            | 93                     |
| B       | 2200           | 45 flats | 2015-2016 | 833           | 0,38            | 18,5          | 81                     |
| C       | 3200           | 18 town houses | 2015-2017 | 1005         | 0,31            | 55,8          | 97                     |
| D       | -              | 90 flats + 113 student flats | 2014-2016 | 1772         | -              | 8,7            | 171                    |
| E       | 14281          | 100 flats | 2014-2016 | 1671         | 0,12            | 16,7          | 161                    |
| F       | 8627           | 121 flats | 2014-2016 | 2244         | 0,26            | 18,6          | 217                    |
| G       | -              | 141 flats | 2013-2016 | 2310        | -              | 16,4          | 223                    |
| H       | -              | 83 flats | 2014-2015 | 3139        | -              | 37,8          | 303                    |
| I       | 6600           | 64 flats | 2014-2016 | 2997        | 0,45            | 46,8          | 290                    |
| J       | -              | 30 flats | 2014-2016 | 2440        | -              | 81,3          | 236                    |
| K       | 18600          | 154 flats | 2014-2017 | 5548        | 0,30            | 30,0          | 543                    |
| L       | 8460           | 167 flats | 2015-2017 | 4518        | 0,53            | 27,1          | 436                    |

Trends in number of transports during projects’ life cycles (as it can be seen in Figure 1) show that the number of transports increase drastically towards the middle of the projects with projects A and K being exceptions.

Figure 1. Trends in number of transports during twelve projects’ life cycles

4.2. Stockholm and Uppsala

The data here shows the trends in number of transports in Stockholm and Uppsala monthly, weekly and per hour. As Figure 2 shows, the number of transports in the Stockholm area increase from the beginning of the year until it reaches to a peak in October, followed by a significant drop towards the end of the year. Uppsala data is based on 12 on-going projects. 4 of these projects are in halfway, 4 are in the beginning phase and 4 are completed during the data collection. Trends of number of transports throughout this period show that highest number of transports happen in September and October at the area.
In Stockholm, number of transports remain high between Monday and Thursday (82%), followed by a drop to Fridays (15%), where significantly lower number of transports happen during weekends (see Figure 3). Trends of number of transports during a week in Uppsala is similar to Stockholm. A peak happens on Tuesdays in Uppsala (22%) and on Wednesdays in Stockholm (21%).

In Stockholm, transportations start already at 5:00 with a rapid increase until 7:00 where daily peak is reached, 22% of transports take place 7-8. A drop in number of transports happen until 9:00 which is followed by a jump at 10:00 (20%). After 10:00, a slow reduction happens until 14:00, followed by a faster reduction in number of transports until 17:00 (see Figure 4). In Uppsala, the number of transports start to increase from 4:00 and makes the peak of the day at 7:00, 25% of transports take place 7-8, followed by a gradual reduction until 16:00. Between 11:00 and 12:00 a small increase happens in number of transports, similar to the jump between 9:00 and 10:00 in Stockholm.

**Figure 2.** Monthly transports in the smaller areas of Stockholm and Uppsala

**Figure 3.** Transport trends of the smaller areas of Stockholm and Uppsala based on weekdays

**Figure 4.** Hourly transport trends of the smaller areas of Stockholm and Uppsala
5. Discussion and conclusion
The transport impact of the construction industry is large; the average number of transports per flat is 6 to 81 transports. Considering that a minimum of 141200 new flats were built at 2017 in Sweden [27], CO₂ emissions for the same year from construction transports were at least 422800 tons CO₂. Annual CO₂ emissions due to housing construction (including refurbishment) in Sweden are 4 MtonsCO₂ [28], which means more than 10% of the emissions come from transports. Clearly, number of transports are a strong indicator of GHG emissions and transport GHG emissions should be considered as a negativity of construction projects. Being unclear about who is responsible of GHG emissions of transportation leads to two major drawbacks: (i) difficulties in collecting data and (ii) difficulties of taking necessary actions to reduce environmental harm of transportation. Thus, with further research, aim is to collect data from more projects and to capture other types of data needed to increase the accuracy in the estimations of the transport impact of construction.

The choice between efficient logistics considering the time pressure in construction projects and logistics with reduced GHG emissions is a difficult one, however with better logistics solutions and planning, both goals can be achieved [13]. Previous studies (e.g. [1]) show that CLS can reduce construction traffic significantly (up to 80% in some phases of projects) or can be used to change the traffic pattern of projects [20]. This paper contributes to a better understanding of the transport patterns of construction projects and thereby the possibilities of decreasing GHG emissions. The results identified several peak points in number of transports: (i) a peak is reached towards halfway of the lifecycle of projects, (ii) the number of transports increase towards the end of the year, (iii) the number of transports remain high between Monday and Thursday, while a small number of transports happen during the weekends and (iv) daily peak for number of transports is reached at 7:00 while very few transports happen after office hours. By relying on these results, better decisions can be made on which CLSs to implement in different types of projects as well as different phases of the projects. Potential impacts of different policies by municipalities such as off-peak deliveries or environmental zones can be estimated more accurately. For example, off-peak deliveries are expected to have a large potential impact on decreasing the congestion of cities.

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