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Containerized Truck Movements in Sweden Payload and Empty Trip Modeling

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ABSTRACT

Container flows account for 12% of truck traffic in Sweden. Unlike other freight, container truck movements mostly involve import or export cargo that begins or ends at ports. However, containerized cargo has different payloads and empty trip patterns. Hence, this paper analyses container truck flows in Sweden (2016–2019) using Trafikanalys data, focusing on empty container movements. Two demand models are presented: one estimates truck payloads to convert cargo weight into truck trips, and the other predicts the likelihood of empty container transport. Empty containers made up 44%–46% of vehicle numbers and 32%–33% of vehicle kilometers in the given period. The results show that payload and empty trips are notably affected by factors such as origin, destination, and industry sector. This paper concludes with the presentation of the model application, final observations, and recommendations for future research. Key suggestions for further investigation include applying these models to estimate empty container traffic and conducting case studies to assess various policy impacts on reducing empty container movements.

1 | Introduction

International container shipping was heavily affected by the recent pandemic where freight rates had huge fluctuations that created uncertainties in the global supply chains (Zheng and Jiang 2025). Therefore, the estimation of freight demand models at regional or national levels is crucial for the public sector and policymakers. These models facilitate the effective planning of policies and infrastructure developments to achieve desired outcomes, such as reductions in total vehicle distance traveled, pollution, emissions, traffic congestion, and noise. Despite their broad range of practical applications, national freight modeling remains limited to cargo weight estimation and mode choice modeling in a few countries (de Jong et al. 2016). A significant challenge in freight modeling is the insufficient availability of data containing appropriate variables at the necessary level of detail. For example, while the Commodity Flow Survey (CFS) dataset is recognized as the primary source of national freight data in both the United States and Sweden, it possesses certain limitations when it comes to estimating freight demand. The CFS data served as the basis for developing econometric models to estimate freight production weights (Holguín-Veras et al. 2017) and mode choice between truck and rail (Holguín-Veras et al. 2021) in the United States. Similarly, the freight demand models for Sweden based on the CFS data include the most comprehensive freight model popularly known as SAMGODS (Swahn 2001) and a stochastic logistic model developed in (Abate et al. 2019). A significant limitation of current national demand models lies in their ability to assess the true effects of freight transportation on infrastructure networks—such as those involving trucks, rail, and waterways—in terms of vehicle flows. These models are generally commodity-based, providing outputs in cargo weight rather than in the number of vehicles transported (de Jong et al. 2016), except a few studies at the urban level focused on estimating freight demand at the vehicle level using freight trip generation models instead of freight generation (Ramirez-Rios et al. 2023). The vehicle flows were often inferred from these weights using secondary datasets such as average payloads, traffic counts, and empty trip shares (Kalahasthi et al. 2022). Hence, the quality of freight demand estimates highly depends on the quality of these secondary data. For instance, the availability of advanced mathematical models to calculate payloads and empty trips at higher levels of accuracy could improve the freight vehicle demands estimated from the CFS data.

Converting commodity-based freight demand models to trip-based models is challenging because there is no payload model for estimating loaded trips, and empty vehicle trips must also be evaluated. Figure 1 illustrates how payload and empty trip models convert commodity flows into vehicle flows between origins and destinations. The payload model calculates loaded trips from cargo flows, while the empty trip model estimates total vehicle trips, including both loaded and empty trips. Payload refers to the cargo weight a vehicle carries—typically less than its designed capacity. Multiple mode and vehicle type combinations are possible for transporting cargo, but while national-level models estimate tonnage shares, determining vehicle flows by mode remains difficult (Rich et al. 2009; Abate and de Jong 2014; Holguín-Veras et al. 2021). The number of loaded vehicles needed to transport a specific weight is influenced by factors such as cargo type, density, packaging, and vehicle capacity. As a result, a payload model is used to convert cargo flows into loaded vehicle flows by accounting for these variables. The absence of an appropriate payload model has been encountered in the previous freight studies. For instance, Jansuwan et al. (2017) used an equivalent factor for truck payloads (a single value for each state) based on the vehicle inventory and used a survey collected by the US Department of Transportation (Bureau of Transportation Statistics 2021). Due to a lack of data, Kalahasthi et al. (2022) the freight demand model was estimated by considering various scenarios for truck and rail payloads for vehicles in Bangladesh. Based on the authors' knowledge, there are currently no existing studies devoted solely to the development of a payload model. Hence, one of the objectives of this research is to fill this gap by estimating a payload model for containers transported by trucks in Sweden.

Another vital aspect in converting commodity to trips is the empty trip model. Past studies found that a significant portion of freight trucks (15%–40%) and containers on the roads belong to empty trips (Castrellon et al. 2023), which are inevitable due to imbalances in supply and demand. However, it is found that a simple matching of imbalances in the freight generation among the zones does not capture the actual behavior of empty truck trips (Tavasszy and De Jong 2013). Hence, one of the notable approaches for capturing the empty trips is the Noortman and Van Es′ (NVE) model, which has been used in several studies (Noortman and Van Es 1978). The NVE model assumes that the empty trips between an origin and a destination could be approximated as a factor of loaded trips in the opposite direction. An approximate value of the NVE empty trip factor is often estimated from the total traffic counts, independent of other salient features, for example, truck type, origin, destination, and commodity type (Müller et al. 2012; Kalahasthi et al. 2022). When the empty trip data are available, the NVE model is improved by incorporating higher order trip chain behavior (Holguín-Veras and Thorson 2003; Holguín-Veras et al. 2010), vehicle and commodity type (Raothanachonkun et al. 2007). Other methods for empty trip modeling include regression models (Gonzalez-Calderon et al. 2021), discrete choice modeling (Rich et al. 2009; Moeckel and Donnelly 2016), optimization methods (Mesa-Arango et al. 2013) and, Genetic Algorithm (Waller et al. 2021).

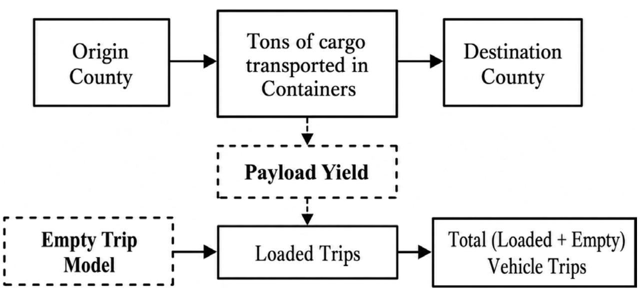

FIGURE 1 | Schematic of estimating container vehicle flows.

Therefore, the purpose of this research is to contribute to the freight transport community and policymakers by developing modeling techniques for payload and empty trips on the case of national container truck flows in Sweden. The truck traffic data used in the study is sourced from Trafikanalys—Transport Analysis—a Swedish government agency responsible for compiling official statistics in the transport sector (Trafikanalys 2022a; Trafikanalys 2022b). Distinguishing container traffic within truck flows is essential, as it predominantly involves import and export cargo, with seaports serving as either the point of origin or destination (Castrellon et al. 2023). Moreover, the travel patterns and decision-making entities, such as shipping companies and dry port operators, for container traffic differ significantly from those associated with non-container traffic (Khaslavskaya et al. 2021). Consequently, incorporating separate models for payloads and empty trips for containers represents a crucial advancement in enhancing existing freight demand models. Addressing payload and empty trip modeling is particularly vital, enabling commodity-based freight datasets like CFS to better support the public sector in policy analysis.

The paper is structured as follows: Section 2 outlines the study area and data; Section 3 details the methodology; Section 4 discusses results and analysis; Section 5 covers model application; and Section 6 offers conclusions, limitations, and future directions.

2 | Research Setting

This study focuses on Sweden, Europe's fifth largest country by area, with a population exceeding 10 million (Swedish Institute 2025). Major cities include Stockholm, Gothenburg, and Malmo, while key seaports are Gothenburg, Trelleborg, Lulea, and Stockholm. The key exports are vehicles, machines, pharmaceuticals, and electronics (Swedish Institute 2025). Sweden is divided into statistical territories based on the Nomenclature of Territorial Units for Statistics (NUTS). NUTS in Sweden have a maximum of three digits—three "Lands" at a 1-digit level, eight "National Areas" at a 2-digit level, and 21 regions called "Counties" at a 3-digit level (Figure 2).

The dataset used in this research is the confidential version of Swedish road goods transport data obtained from

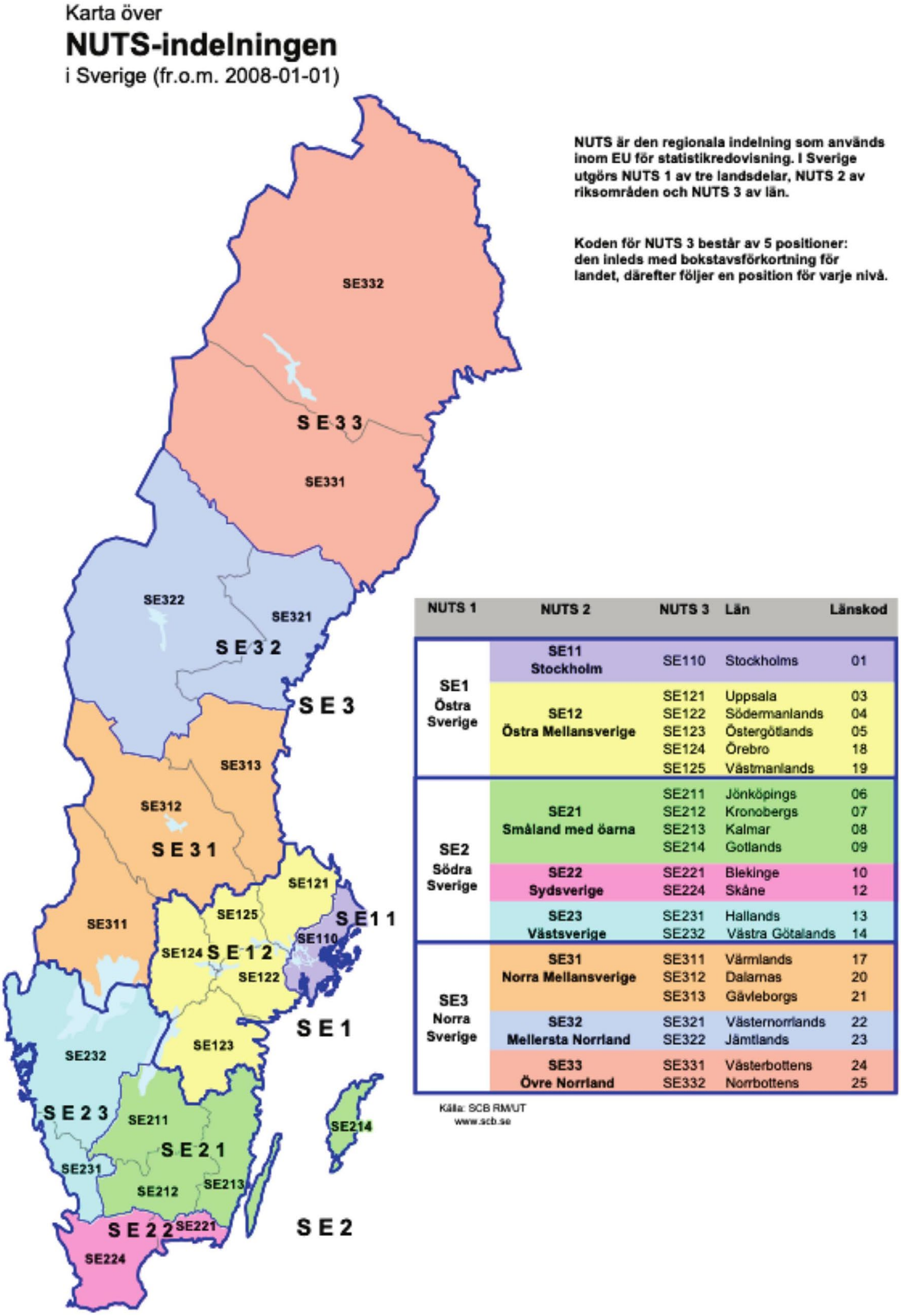

FIGURE 2 | Counties in Sweden (SCB Statistics Sweden 2022).

Trafikanalys for 4 years from 2016 to 2019 (Trafikanalys 2022a; Trafikanalys 2022b), where the respondents are truck owners of Swedish-registered heavy commercial vehicles (HCVs). The container flows have been included in the dataset since 2016. In 2019, Sweden had about 84,000 registered trucks over 3.5 tons, covering roughly 2900 million vehicle kilometers (Trafikanalys 2020; Trafikanalys 2022a; Trafikanalys 2022b). The road goods transport data serves as a sample for modeling and analyzing payloads and empty trips. It is derived from a mandatory annual survey of around 12,000 Swedish registered trucks, representing approximately 14%, and includes both container and non-container traffic (Trafikanalys 2022a; Trafikanalys 2022b). The potential variables include binary variable for containerized cargo if the container is loaded or empty, Origin and Destination (OD) at county level (3-digit NUTS), industry sector at 5-digit Swedish Standard Industrial Classification (SNI) code (Statistiska Centralbyrån 2007), weight of cargo including the container weight, kilometers driven, and number of axles. After separating container flows from all truck trips, the dataset is split into loaded and empty containers (see Figure 3); where international trips account for less than 1%.

2.1 | Payload Data

Figure 3 shows data preparation for payloads, defined as the cargo weight inside a container, not including the empty container's weight. Since loaded container data lacks the empty container weight, payloads must be estimated from available information. The survey collects data on the "total weight" carried by a truck, that is, for loaded container flows, the "total weight" is equal to the sum of the weights of an empty container and the cargo inside it.

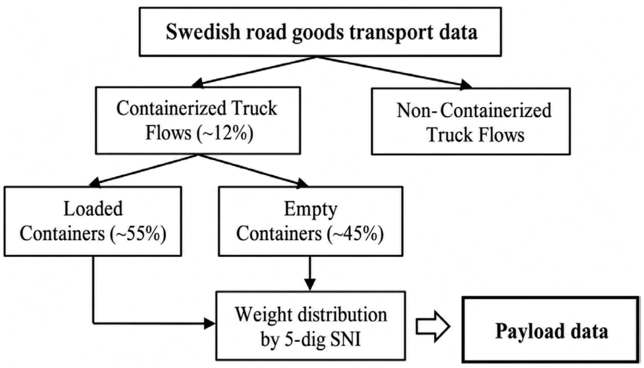

FIGURE 3 | Payload data preparation.

Similarly, for empty container flows, the "total weight" is equal to the weight of the empty container. Hence, an approximate value for the payloads of the loaded container trucks was obtained by subtracting the weight of the empty containers from the "total weight" on the trailer carrying the loaded container (see Equation 1).

$$\begin{aligned} \textit{Container Payload} &= \textit{Weight on the trailer with loaded container} \\ &\quad - \textit{Weight of empty container} \end{aligned} \tag{1}$$

The empty container weights are imputed in the loaded container dataset, assuming a uniform distribution across the industry sectors at 5-digit SNI. For example, for the industry sector "freight transport by road (SNI 49410)" an empty container weight of 2 tons is assigned to 23% of the sample randomly selected from the loaded container data, 2.5 tons is assigned to 38% of the sample and 4 tons is assigned to 39% of the sample (see Table 1).

Table 1 presents the 10 sectors with the largest sample sizes in the empty container dataset. The complete dataset includes 159 industry sectors, and the sectors presented in the table represent approximately 83% of the sample. The "freight transport by road" sector (SNI 49410) accounts for 53% of the sample, while "site preparation" (SNI 43120) represents 14%. Table 1 indicates that the proportion of empty containers and the distribution of their weights differ notably among industry sectors. Thus, industry sector should be included as an independent variable in both the payload and empty trip models.

Around 2650 observations from loaded container weights are removed from the analysis as they contain abnormal values, that is, the weight of an empty container larger than 5 tons and the weight of a loaded container less than 5 tons. The mean payload is 17.5 tons, with a standard deviation of 10.7 tons, a minimum value of one ton, and a maximum of 78.5 tons. The Shapiro–Wilk test results (p value < 0.005) suggest that the payload distribution can be approximated by a normal distribution. Therefore, a linear regression model may be applied to estimate the payload.

TABLE 1 | Data description for loaded and empty container road transport.

						Empty weight		
No	**SNI**	**Description**	**Obs.**	**Empty**	**%**	**2 ton**	**2.5 ton**	**4 ton**
1	49410	Freight transport by road	15,421	5600	36%	23%	38%	39%
2	43120	Site preparation	4192	1796	43%	38%	42%	20%
3	38110	Collection of non-hazardous waste	1283	309	24%	38%	37%	26%
4	52290	Other transportation support activities	695	287	41%	34%	38%	28%
5	43991	Renting of construction or demolition equipment	411	209	51%	35%	52%	13%
6	77320	Renting/leasing of construction machinery	573	184	32%	51%	40%	10%
7	41200	Construction, residential/non-residential buildings	346	152	44%	45%	47%	8%
8	43,999	Other specialized construction activities	440	151	34%	36%	50%	14%
9	38,320	Recovery of sorted materials	379	134	35%	39%	38%	23%
10	8120	Operation of gravel and sand pits; mining of clays	282	124	44%	37%	30%	33%

2.2 | Empty Container Data

The truck dataset from 2016 to 2019 includes 250,000 samples, with about 12% (29,000) representing container truck flows—roughly 6000 to 8000 observations per year. Table 2 presents data on the number of vehicle trips and vehicle kilometers traveled by container trucks within Sweden. The proportion of empty trucks ranges from 44% to 46% for the number of vehicle trips, and from 30% to 35% for vehicle kilometers, across the four-year period. However, the trip distance was found to be insignificant in the model when the ODs were included. In 2018, empty trips accounted for the highest share of both vehicle trips and vehicle kilometers. Loaded containers averaged 95 km per trip, while empty ones averaged 53 km, indicating trucks are frequently rerouted to minimize empty travel distances.

Empty container trips were analyzed by county-level OD pairs. Around 77% occur within the same county, with Västra Götalands, Skane, and Stockholm counties accounting for 37% of the sample. Table 3 presents the proportion of empty truck container trips among the 21 country OD pairs. Approximately 36% of OD pairs have more than 40% empty trips (highlighted), while around 33% have less than 10% empty trips. Among the highlighted OD pairs, more than 10% of the OD pairs have larger than 90% of the container truck movements being empty, where the destination counties for these OD pairs constitute major exporters with minimum demand for imports. The table also displays significant trip chain behavior where the container travels from an origin to various destinations instead of plying between an OD, that is, the share of empty trips forward and return between an OD does not add up to one. The Analysis of Variance (ANOVA) test indicated that the within-group variation yielded a p value below 10%, demonstrating that the proportion of empty container share differs significantly across the counties. The methodology and modeling results for payloads and empty trips are presented in the next sections.

TABLE 2 | Data on the number of vehicle trips and vehicle kilometers traveled by container trucks.

Year	Empty	Loaded	Total	% Empty
Number of vehicle trips				
2016	3013	3796	6809	44.25%
2017	3319	3923	7242	45.83%
2018	3721	4304	8025	46.37%
2019	3221	3938	7159	44.99%
Total	13,274	15,961	29,235	45.40%
Vehicle kilometers				
2016	1,70,854	3,94,564	5,65,418	30.22%
2017	1,75,582	3,86,079	5,61,661	31.26%
2018	1,92,454	3,62,279	5,54,733	34.69%
2019	1,66,982	3,76,955	5,43,937	30.70%
Total	7,05,872	15,19,877	22,25,749	31.71%

3 | Methodology

A linear regression model is used for payload analysis, while a binary logit model estimates the probability of an empty trip. The rationale for selecting the independent variables is as follows. The payload and empty trip models were selected based on prior research, and both were found to depend on the origin, destination, and industry sector (or commodity type). For instance, a truck carrying a denser commodity or transporting to a particular destination is found to have a higher payload or shipment size (Holguín-Veras et al. 2021). Similarly, higher-order empty trip models that consider trip chaining behavior have shown that truck empty trips also depend on origin, destination, and commodity type (Gonzalez-Calderon et al. 2021). However, none of these studies examined model calibration, including all these variables, mainly due to data availability constraints—which constitutes the key research gap this study addresses by building an extensive dataset within the limited access obtained from (Trafikanalys 2022a; Trafikanalys 2022b). The model forms and the results for payload and empty trips are explained below. Statistical software STATA version 14.2 is used for calibration (StataCorp, L. 2007).

3.1 | Payload Model

The model to estimate payload in kilograms is shown in Equation 2. Equation 2 is a linear model calibrated using Ordinary Least Squared (OLS) methods. Except for the "number of axles" (continuous), all other variables, that is, origin, destination counties, industry sector, and year, are categorical. The interaction terms among these categorical variables were found to be statistically insignificant. The linear model provided a better fit than nonlinear models with logarithmic transformations.

$$Payload = \beta_0 + \beta_1 Axles + \sum_i \beta_i O_i + \sum_j \beta_j D_j + \sum_k \beta_k I_k + \sum_m \beta_m Year_m + \varepsilon \tag{2}$$

where

Axles = Number of axles of the truck, varies among 2, 3, 4, or 5.

O_i, D_j = *Origin and Destination Counties respectively.*

I_k = *Industry sector at 5-digit SNI level.*

$Year_m$ = *Year among 4 years* that is, *2016–2019.*

ε = *Error term.*

3.2 | Empty Trip Model

The empty trips could be modeled as a probability of a container truck being empty (P_e) as the dataset clearly differentiates between the loaded and empty containers. A binary logit model shown in Equations 3 and 4 is estimated. The dependent variable is a binary variable equals to one if the truck is carrying an empty container, otherwise (if the truck carries a loaded container) equal to zero. The independent variables are origin, destination counties, and industry sector. Other variables for

TABLE 3 | Share (fraction) of empty truck container trips between OD counties.

OD county	Stockholms	Uppsala	Södermanlands	Östergötlands	Jönköpings	Kronobergs	Kalmar	Gotlands	Blekinge	Skåne	Hallands
Stockholms	0.5	0.6	0.6	0.3	0.2	1.0	0.2		0.0	0.5	0.0
Uppsala	0.5	0.5	0.3	1.0				0.0		0.0	
Södermanlands	0.4	0.8	0.5	0.5	0.2		0.0			0.5	0.0
Östergötlands	0.1	0.4	0.3	0.5	0.3	0.2	0.6		1.0	0.3	0.2
Jönköpings	0.0		0.5	0.1	0.5	0.4	0.5	0.3	0.7	0.1	0.2
Kronobergs	0.0			0.0	0.3	0.5	0.6		0.4	0.5	0.3
Kalmar	0.5	1.0		0.4	0.2	0.3	0.5		0.2	0.4	0.2
Gotlands	0.0				0.0	0.0	0.0	0.5			0.0
Blekinge	0.3			0.0	0.3	0.4	0.5		0.5	0.5	0.0
Skåne	0.2	0.0	0.0	0.1	0.2	0.4	0.1		0.5	0.5	0.4
Hallands	0.5	0.0		0.0	0.7	0.4	0.5	0.5	0.9	0.5	0.5
Västra Götalands	0.1	0.0	0.1	0.3	0.2	0.4	0.2	0.0	0.8	0.4	0.4
Värmlands	0.1	0.3	0.5	0.1	0.3	0.0	0.0			0.0	0.0
Örebro	0.0	0.3	0.7	0.2	0.2		1.0		0.0	0.2	0.1
Västmanlands	0.4	0.5	0.8	0.4	0.8	1.0	0.0				0.0
Dalarnas	0.3	0.3	0.7	0.0	0.5					0.0	
Gävleborgs	0.2	0.6	0.3	0.4	0.3	0.0			0.3	0.0	
Västernorrlands	0.0	0.0	0.0	0.0			0.0			0.1	
Jämtlands	0.0		0.0		0.3						
Västerbottens	0.0			0.0	0.0					0.0	0.3
Norrbottens	0.0	0.0		1.0	1.0						

OD county	Västra Götalands	Värmlands	Örebro	Västmanlands	Dalarnas	Gävleborgs	Västernorrlands	Jämtlands	Västerbottens	Norrbottens
Stockholms	0.3	0.3	0.6	0.4	0.3	0.6	0.0	0.5	0.0	0.0
Uppsala	0.3	0.3	0.5	0.6	0.2	0.4	0.7	0.5		0.0
Södermanlands	0.2	0.2	0.2	0.3	0.0	0.7	0.0	1.0		0.0
Östergötlands	0.3	0.3	0.1	0.2	0.2	0.4	0.0		0.0	0.0

(Continues)

TABLE 3 | (Continued)

OD county	Västra Götalands	Värmlands	Örebro	Västmanlands	Dalarnas	Gävleborgs	Västernorrlands	Jämtlands	Västerbottens	Norrbottens
Jönköpings	0.5	0.0	0.0	0.2	0.0	0.5	0.0	1.0	0.0	0.0
Kronobergs	0.3	1.0	0.0	0.0		0.0		0.0		
Kalmar	0.5		0.0	0.5						
Gotlands	0.0									
Blekinge	0.1	0.0				0.9			0.0	
Skåne	0.4	0.2	0.0	0.0	0.0	0.0	0.0		0.0	
Hallands	0.5	0.0	0.5	0.0	0.0				0.7	
Västra Götalands	0.5	0.4	0.1	0.1	0.1	0.3	0.0	0.0		
Värmlands	0.4	0.5	0.3	0.2	0.6	1.0	0.3	0.0		0.0
Örebro	0.4	0.5	0.5	0.2	0.4	0.5	0.0	0.0	0.3	0.0
Västmanlands	0.8	0.3	0.6	0.5	0.3	0.2	0.0			1.0
Dalarnas	0.3	0.2	0.2	0.4	0.5	0.4	0.0	0.0	0.0	
Gävleborgs	0.4	0.0	0.1	0.6	0.3	0.5	0.3	0.3	0.3	0.0
Västernorrlands	0.2	0.0	0.3	0.4	1.0	0.5	0.5	0.5	0.2	0.1
Jämtlands	0.5		0.3	1.0	1.0	0.3	0.4	0.5	0.4	0.0
Västerbottens	0.0		0.0	0.0	0.5	0.5	0.5	0.6	0.4	0.6
Norrbottens		1.0	0.0	0.3	0.0	0.0	0.5	0.5	0.4	0.5

Note: Highlighted cells have larger than 0.4; Empty cells indicate no trips happen between these OD pairs.

example, year, number of axles, and the interaction terms are statistically insignificant.

$$P_e = e^{V_e} / \left(1 + e^{V_e}\right) \tag{3}$$

$$U_e = V_e + \delta_e = \alpha_0 + \sum_i \alpha_i O_i + \sum_j \alpha_j D_j + + \sum_k \alpha_k I_k + \delta_e \tag{4}$$

where

U_e = *Total utility of a truck carrying an empty container.*

V_e = *Systematic component of the utility of a truck carrying an empty container.*

O_i, D_j = *Origin and Destination Counties respectively.*

I_k = *Industry sector at 5-digit SNI level.*

δ_e = *Error term.*

4 | Results and Analysis

The payload model for the truck container flows in Sweden is shown in Table 4. The results show that 17 out of 21 destinations are significant in deciding the payload transported, while just six origin counties were found to be significant. More than 40 industry sectors out of 159 were significant. Unlike the empty trip model (see Table 5), where 12 origin and 20 destination counties were significant, while just 17 industry sectors affected the probability of the trip being empty. The coefficient of determination is a little more than 0.1, indicating that the predicted value from this model is better than using an average payload for all container truck flows—which is typically used in freight research (Jansuwan et al. (2017)). Other model forms provided a poor fit. Irrespective of the goodness of fit, the model provides valuable insights into significant variables that affect the payload and a way forward for future research to further improve the data collection and modeling. The number of axles is associated with payload capacity, with each additional axle corresponding to an increase of approximately 1.8 tons in payload. Since the 3-axle (57%) and 4-axle (40%) trucks are the majority in container transportation, none of the estimated payloads would give negative values, that is, the conceptual validity is cross-checked.

The industry sectors with higher payloads are "Manufacture of other articles of concrete (SNI 23690)" and "Warehousing and storage (SNI 52100)", while "Manufacture of metal structures (SNI 25110)" and "Wholesale of other machinery (SNI 46699)" have the least. In sectors with lower payloads, containers are often loaded to capacity based on volume rather than weight, due to the shape of cargo such as machinery and metal structures. The county "Stockholms" is chosen as the base case for both origin and destination. In 2018, payloads were slightly lower compared to other years. It is found that the destination county is an important factor in accounting for payload variability, with 17 out of 21 destination counties identified as statistically significant, compared to just six origin counties. Trips originating from "Jönköpings" and "Kalmar" have an average payload larger than that of "Stockholms" by about three tons. Whereas, the containers destined for "Blekinge" and "Norrbottens" have payloads of approximately four tons more. The counties "Jönköpings" and "Skåne" have almost equal payloads as that of the base case. For instance, a container truck with three axles, either originating or destined for Stockholm, carrying farming goods, had an average payload of around 18 tons in 2019. The same container truck, however, would have weighed about 36 tons on average if it carried concrete products. Hence, the model could be applied to estimate the payload between an origin and destination county for a given industry sector. These models aim to complement current research on freight generation, that is, estimating the tons of cargo transported (usually by industry sector and county using economic census data) and converting them into vehicle flows by truck type.

4.1 | Empty Trip Model

Table 5 presents the binary logit model for truck empty container flows in Sweden. Unlike the payload model (see Table 4), the empty trips are more dependent on the location; origin and, specifically, the destination counties than the industry sector. For instance, the payload was dependent on more than 40 industries and just six out of 21 origin counties. Whereas, the empty trips were affected by just 17 industries. However, more than 10 origins and 20 out of 21 destinations were found to influence a trip being empty significantly. County "Västerbottens" is chosen as the base case for both origin and destination. All 20 counties are statistically significant destinations with positive coefficients (the probability of being empty is higher than the base county). Twelve origin counties exhibit statistically significant negative coefficients, indicating that the likelihood of truck container trips originating from these counties being empty is lower compared to the base county. A container truck originated at the remaining nine counties would have higher probability of the trip being empty. The county of origin exhibiting the highest elasticity, at −0.15, is "Kalmar", which indicates that when a trip originates from "Kalmar", the likelihood of the container truck being empty decreases by 15%. Other origin counties with higher elasticities (values in parenthesis) are "Kronobergs" (−0.14), "Västra Götalands" (−0.13), and "Blekinge" (−0.13). The five counties with the highest elasticity values among the destinations are "Blekinge" (0.39), "Västra Götalands" (0.38), "Skåne" (0.37), "Kalmar" (0.37), and "Jämtlands" (0.35). The industries with the highest probability of empty truck container trips are the manufacture of concrete (SNI 23690), trade electricity (SNI 35140), and waste removal services (SNI 49420). Whereas, the ones with the least chances include, postal services (SNI 53100), Silviculture (SNI 2102) and Logging (SNI 2200). Hence, the strategies must focus on the key industries and location that contribute the higher share of empty trips.

Four counties—Blekinge, Västra Götalands, Skåne, and Kalmar—rank among the top five for elasticity as both origins and destinations. For example, Västra Götalands is more likely to receive empty trips than to send them. Notably, all four counties host major Swedish ports where imports exceed exports. The industry sector with the highest probability of having an

TABLE 4 | Payload models for truck container transport.

SNI	Industry sector	Coeff	*p*	Variable	Coeff	*p*
1110	Growing of cereals (except rice)	6105.51	0.000	Origin county		
1133	Growing of vegetables in the open	20,186.84	0.000			
1420	Raising of other cattle and buffaloes	11,337.54	0.000			
1500	Mixed farming	8580.98	0.000	Hallands	1699.46	0.002
2102	Silviculture	4286.48	0.019	Jönköpings	3488.16	0.000
2200	Logging	12,840.63	0.000	Kalmar	3226.64	0.000
8120	Operation of gravel and sand pits	11,127.94	0.000	Kronobergs	2694.54	0.000
10,910	Manufacture of feeds for farm animals	9063.52	0.033	Östergötlands	1514.32	0.004
16,101	Sawmilling	9599.99	0.000	Västmanlands	2057.58	0.008
16,103	Impregnation of wood	11,972.25	0.001	Destination county		
16,291	Manufacture of wood fuels[a]	3758.63	0.079			
23,610	Manufacture of concrete products	10,668.70	0.000			
23,630	Manufacture of ready-mixed concrete	3899.94	0.006	Blekinge	4953.62	0.000
23,690	Manufacture of other articles of concrete	26,388.30	0.012	Dalarnas	3310.81	0.000
25,110	Manufacture of metal structures	−7129.77	0.053	Gotlands	2372.08	0.015
31,011	Manufacture of office and shop furniture	−4943.85	0.001	Hallands	2533.25	0.000
31,022	Manufacture of kitchen fittings[a]	−4589.22	0.069	Jönköpings	1103.94	0.023
33,190	Repair of other equipment	13,343.96	0.000	Kalmar	2494.42	0.002
38,110	Collection of non-hazardous waste	4106.38	0.000	Kronobergs	3051.02	0.000
38,120	Collection of hazardous waste	12,519.35	0.017	Norrbottens	4011.86	0.000
38,210	Treatment/disposal of non-hazard waste	11,094.89	0.003	Östergötlands	1305.70	0.017
42,990	Construction of other civil projects	4307.28	0.009	Skåne	1261.21	0.000
43,110	Demolition	7328.67	0.026	Södermanlands	1654.84	0.012
43,120	Site preparation	2821.18	0.000	Uppsala	1594.64	0.013
43,320	Joinery installation	3561.76	0.011	Värmlands	2248.95	0.000
43,999	Other specialized construction activities	1919.72	0.017	Västerbottens	2042.72	0.000
45,201	Maintenance and repair of motor vehicles	7477.81	0.000	Västernorrlands	2745.29	0.000
46,630	Wholesale of mining, construction	−5273.00	0.016	Västmanlands	2796.75	0.000
46,699	Wholesale of other machinery	−7095.86	0.031	Västra Götalands	2120.27	0.000
46,710	Wholesale of solid, liquid fuels	15,426.93	0.000	Constant and other variables		
46,731	Wholesale of construction materials	5167.50	0.011			
49,410	Freight transport by road	7082.32	0.000			
49,420	Removal services[a]	−6085.22	0.064	Year 2018	−690.5288	0.001
52,100	Warehousing and storage	21,589.36	0.000	No of Axles	1774.97	0.000
52,290	Other transportation support activities	2101.71	0.002	Constant	4356.97	0.000
68,201	Renting/operating of dwelllings	10,364.76	0.000	Model attributes		
68,203	Renting of own or leased other premises	7707.13	0.036			
74,900	Other professional, scientific activities	21,543.14	0.004	Number of obs	13,311	

(Continues)

TABLE 4 | (Continued)

SNI	Industry sector	Coeff	p	Variable	Coeff	p
77,310	Renting/leasing of agricultural machinery	18,832.32	0.000	F(69, 13,241)	24.24	
78,200	Temporary employment agency activities	8078.19	0.000	Prob > F	0	
79,110	Travel agency activities	20,577.55	0.000	R^2	0.11	
81,290	Other cleaning activities	6936.10	0.045	Adj R^2	0.11	
82,990	Other business support service activities[a]	5173.29	0.085	Root MSE	10169.00	
96,011	Washing and (dry-)cleaning	−5283.21	0.011	df	69	

[a]Significant at 10% level; other coefficients are significant at 5% level.

empty container trip is "Trade of electricity (SNI 35140)" with elasticity of 0.62; followed by "Manufacture of other articles of concrete (SNI 23690)" with elasticity of 0.47. The lower value of pseudo R^2 indicates that there are other unknown influencing variables unavailable in the dataset e.g., shipping line the container belongs to, typology, container type, and trip chain behavior; in addition to origin, destination, and industry sector which needs to be included in the model to account for the unexplained variance. Nevertheless, this model provides a way to improve the estimates of empty container market shares, compared to the constant portion assumption by the widely used Noortman and Van Es′ model (Noortman and Van Es 1978, Müller, Wolfermann et al. 2012).

5 | Model Application

The empty trip and payload models in Tables 4 and 5 assist in improving the estimation of freight transportation demands and policy implications by effectively complementing the Swedish CFS, which is used by the Swedish Transport Administration (STA) for freight traffic analysis (Trafikanalys 2018). The CFS estimates the Origin–Destination (OD) flows between NUTS regions (see Figure 2) in terms of the weight of cargo from different industry sectors (by SNI code) and modes of transport. The payload models assist in converting weights provided by the CFS data for the road mode into freight traffic flows between the regions by different vehicle (truck) types. The empty trip model estimates the traffic movement by empty container truck types.

Figure 4 presents the practical application for payload and empty trip models. The first step is to extract the commodity flows from the CFS data in terms of containerized tons transported by truck between NUTS regions in Sweden. The weight of the cargo from the CFS data combined with the payload model (see Table 4) could be used to estimate the number of loaded trucks required to transport the cargo between an OD. Instead of an average payload factor for all trucks transported in Sweden, the payload model considers the industry (by SNI code), origin, and destinations by counties to estimate the payloads for each OD flow by SNI for a container truck with a given number of axles. Since the number of axles is an input for the payload model, the estimation of loaded trips requires the share of trucks by a number of axles plying between an OD, which needs to be obtained from the traffic counts such as toll plazas and detectors. For example, the CFS gives the weight of construction materials (SNI 46731) transported between Kalmar to Blekinge in number of tons. The payload model would estimate the number of trucks, either 3-axle, 4-axle, or 5-axle trucks required to transport. In practice, the freight traffic responsible for transporting concrete materials is likely to include trucks with 3, 4, and 5 axles. Therefore, it is essential to gather data on the composition or distribution of truck types operating between Kalmar and Blekinge.

Once the loaded truck flows (T_L) are obtained, the empty trip model (Table 5) could be applied to estimate the total trips (T), which is equal to the sum of loaded (T_L) and empty (T_E) truck container trips. The empty trip model estimates the market share of empty trips (S_E) based on the SNI, origin, and destination. The total vehicle trips (T) could be obtained from Equation (5).

$$T = T_L + T_E = T_L / \left(1 - S_E\right) \tag{5}$$

A sample application of the models to publicly available (aggregate) CFS data would demonstrate the potential of this research for policy and strategy interventions. For instance, in 2021, the total cargo (including all industry sectors) transported from the county Stockholms to county Västra Götalands was 516,000 tons. The payload model estimates an average payload across all industry sectors (assuming 3-axle trucks) for this origin–destination pair as around 11.8 tons and the market share of empty trips (mean for all industry sectors) as 0.35, which is in line with the previous research (Gonzalez-Calderon et al. 2021). These estimates translate into nearly 43,700 loaded truck trips, trucks and 67,700 total trips, comprising loaded and empty trips. These predicted values are reasonable when compared with the vehicle kilometers traveled published by Trafikanalys (2022a), Trafikanalys (2022b). For better estimates, disaggregate commodity flow data by industry sector, truck type, and commodity type should be available, which could be a substantial contribution to future research. The total vehicle trips (T) comprise different truck types, which in turn helps in quantifying the container truck impacts on society, for example, vehicle kilometers traveled, emissions, and congestion. In addition to the CFS, these models could be complemented with any relevant national-level freight data. These models could also be incorporated into the SAMGODS system to assist freight analysis in Sweden (Swahn 2001).

TABLE 5 | Empty trip models for truck container transport.

SNI	Industry sector	Coeff	*p*	Variable	Coeff	*p*
2102	Silviculture[a]	−0.50	0.075	Origin county		
				Blekinge	−0.53	0.001
2200	Logging	−0.34	0.057	Gävleborgs	−0.27	0.012
23,690	Manufacture of other articles of concrete[a]	1.94	0.076	Jönköpings	−0.34	0.000
35,140	Trade of electricity	2.54	0.018	Kalmar	−0.61	0.000
38,110	Collection of non-hazardous waste	−0.16	0.029	Kronobergs	−0.57	0.000
38,210	Treatment/disposal of non-hazard waste	0.99	0.020	Örebro	−0.30	0.003
38,320	Recovery of sorted materials	0.43	0.002	Östergötlands	−0.29	0.003
41,200	Residential/non-residential buildings	0.36	0.005	Skåne	−0.48	0.000
42,210	Construction of utility projects for fluids	−0.88	0.021	Södermanlands	−0.38	0.001
43,991	Renting of construction/ demolition equipment	0.37	0.002	Uppsala	−0.26	0.020
49,410	Freight transport by road	−0.20	0.000	Värmlands	−0.36	0.005
49,420	Removal services	1.21	0.002	Västra Götalands	−0.54	0.000
53,100	Postal activities under universal service	−3.01	0.000	Destination county		
77,390	Renting/leasing of other machinery[a]	0.33	0.078	Blekinge	1.60	0.000
78,200	Temporary employment agency activities	−3.32	0.002	Dalarnas	1.05	0.000
81,221	Other building cleaning activities	−0.46	0.054	Gävleborgs	1.37	0.000
85,201	Compulsory comprehensive school education	0.81	0.002	Gotlands	1.12	0.000
Constant and other variables				Hallands	1.10	0.000
				Jämtlands	1.45	0.000
Constant		−0.95	−4.04	Jönköpings	1.14	0.000
				Kalmar	1.52	0.000
Model attributes				Kronobergs	1.38	0.000
				Norrbottens	0.90	0.001
				Örebro	0.92	0.000
Number of obs		25,732		Östergötlands	1.24	0.000
LR Chi2 (50)		702.67		Skåne	1.53	0.000
Prob > Chi2		0		Södermanlands	1.43	0.000
Pseudo R^2		0.02		Stockholms	1.13	0.000
Log likelihood (model)		−17469.335		Uppsala	1.36	0.000
Log likelihood (null)		−17820.67		Värmlands	1.34	0.000
df		51		Västernorrlands	0.90	0.001
AIC		35040.67		Västmanlands	0.90	0.001
BIC		35456.6		Västra Götalands	1.55	0.000

[a]Significant at 10% level; other coefficients are significant at 5% level.

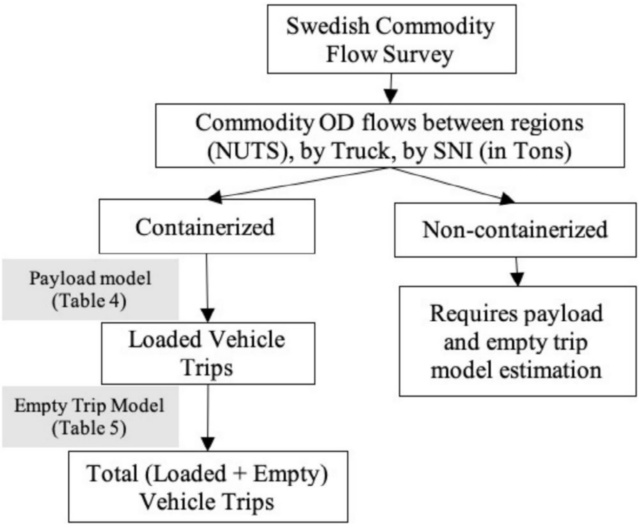

FIGURE 4 | Payload and empty trip model application.

6 | Conclusion

National freight demand modeling is typically conducted at the commodity level, considering factors such as weight, value, or volume of cargo because data available at the national or regional level are generally commodity-based rather than trip-based. In the literature, the commodity flows are converted to vehicle trips based on the assumptions on average values of truck payloads (weight of cargo) and portion (typically a constant share) for empty trips. Instead of using the average values, this paper developed modeling techniques to support the conversion of the commodity-based freight flows to vehicle-based by incorporating various influencing factors, for example, origin, destination, commodity, containerized or non-containerized cargo, and vehicle type. The scope is limited exclusively to container movements by trucks in Sweden. To this effect, the road goods transport data owned by Trafikanalys (2022a), Trafikanalys (2022b) for 4 years (2016–2019) were analyzed for two aspects: (i) payloads of containers on truck, and (ii) empty container movements. In addition, econometric models to predict the payloads (OLS regression) and empty trip (binary logit) shares as a function of origin and destination among 21 counties (3-digit NUTS), industry sector (5-digit SNI) were also estimated.

The findings indicated that the mean payload was approximately 17 tons, with a standard deviation of 10 tons. The payloads are highly dependent on the industry sector, where "Manufacture of other articles of concrete (SNI 23690)", and "Warehousing and storage (SNI 52100)" have the highest values. The payload increases by about 1.7 tons for an additional axle in a container truck. The destination county affects the payloads more than the origin county in Sweden. The empty trip share is between 44% and 46% in the number of vehicles and 30%–35% in vehicle kilometers traveled. Around 36% of OD pairs at the county level have more than 40% of the empty trips. The empty trips are more dependent on the origin and destination counties than the industry sector. Four counties (Blekinge, Västra Götalands, Skåne, Kalmar) affect the probability of empty container trips differently based on whether they serve as origins or destinations; the probability is higher for destinations and lower for origins. The industry sectors with the least probability of a container truck being empty are: "Temporary employment agency activities (SNI 78200)" and "Postal activities under universal service obligation (SNI 53100)". In addition, the possible applications of payload and empty trip models in national freight planning for Sweden were also presented.

This study provides opportunities for future freight transport research and offers recommendations to improve the road goods data collection process. First, the models are currently applicable only to Sweden. The applicability of these models to other countries and regions needs further investigation. Second, the road goods transport data do not distinguish between 20-ft and 40-ft containers, which could significantly impact the modeling, particularly regarding payload. Therefore, it is recommended that the survey include container type in the data collection process. Since the containers often have standard empty weights, the inclusion of the type of container also facilitates the precise calculation of the payloads, which is equal to the total weight of the truck minus the empty container weight. Third, Sweden has 21 counties, which are further divided into 282 municipalities. The modeling was performed at the county level (larger geographic region) since only 25% of the sample had the location of origin and destination at the municipality level (smaller region). Smaller geographic regions would capture the origin–destination flows better by reducing the share of internal trips inside the same region. Fourth, the payload and empty trip models could be improved by incorporating other explanatory variables such as trip distances, seasonal variation, and land use, and also by testing other advancing model forms and machine learning techniques. Finally, similar models should be developed for non-container movements by truck to quantify the total impacts of truck transport. However, the payload and empty trip models developed in this research have potential to enhance the freight transportation planning process and policy decisions and support infrastructure investments in Sweden.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from Trafikanalys. Restrictions apply to the availability of these data, which were used under license for this study. Data are available from the author(s) with the permission of Trafikanalys.

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