Freight Modeling

An Overview of International Experiences

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Compared with passenger transportation modeling, freight modeling is young, and it is developing quickly in different directions all over the world. The objective of this paper is to summarize the international state of the art in freight modeling, with a focus on developments in Europe. Key issues in freight policy that create a growing demand for freight demand modeling are described briefly. Some of them are common to the freight agendas in many places of the world, and some are more pertinent to the European situation. A conceptual framework of the freight system is sketched first. Three emerging areas of innovation in freight modeling that have been driven by the European transport policy context and are relevant for U.S. freight policy are identified: freight–economy linkages, logistics behavioral modeling, and freight trips and networks. The state of the art in these areas is described, and areas of further modeling work are identified. Finally, the main ideas of the paper are summarized, including the challenge of creating new data sources concerning freight flows.

Compared with passenger transportation modeling, freight modeling is young, and it is developing quickly in different directions all over the world. Since the direction of development has depended on local priorities in freight policy, it is not surprising that freight model development has traveled a slightly different path in Europe from the one traveled in the United States. The objective of this paper is to summarize the international state of the art in freight modeling, with a focus on Europe. Three areas of innovation in freight modeling that have typically been driven from a European context but are relevant for U.S. freight policy are discussed:

- Freight–economy linkages,
- Logistics behavior, and
- Freight trips and networks.

There are numerous reviews of freight transport models in the transport modeling literature. They are not repeated here; most can be found through the Freight Model Improvement Program website. In addition, a complete set of references to all available European Union (EU) work on freight modeling is not provided. The account is limited to a selection of key papers in the literature. Recent freight model literature reviews that include European experiences within an international context can be found elsewhere (*1–4*).

The peer review of this paper was conducted by the Committee on Freight Demand Modeling: A Conference on Tools for Public-Sector Decision Making.

Freight Policy Issues and Modeling Needs

Before the main lines of model development in Europe are described, the key issues in freight policy that have created the demand for freight demand modeling in the first place are discussed briefly. Some of them are common to the freight agendas in many places of the world, and some are more pertinent to the European situation.

Table 1 indicates that freight modeling within Europe requires (*a*) more detail (vehicle types, logistics, spatial characteristics) and (*b*) an extension of dimensions of freight modeling into the broader transport system (geographically as well as functionally, i.e., linking transport and the economy).

Clearly, the existence of the EU Common Transport Policy has fostered the development of all kinds of EU-level international models where the attempt has been made to satisfy as many of the above requirements for improvement as possible. In particular, the creation of continental models—where domestic freight and global freight are intertwined, all modes of transport are relevant, and borders play a crucial role—has been typical. Priorities of the individual countries have often developed in parallel with EU policy and EU-level research. The remainder of the paper will focus on the main development lines that have emerged from this national- and EU-level research.

Emerging Lines of Model Development

A conceptual framework based on firm decisions relevant to transportation demand is proposed. This frame resembles the four-step modeling approach but allows (*a*) decision problems that firms face related to freight movements to be taken into account and (*b*) extensions to include operations that are typically less relevant to passenger transport, such as storage (see Figure 1).

Since the advent of transport modeling, freight modeling has gone through a number of major development stages. Knowledge in each of these layers has built up individually, and they have slowly become connected to one another.

The first major national attempt in Europe to describe freight transport flows was in the early 1970s (*5*). These models focused on the layer of trade and used gravity modeling as a main tool. A new impetus to freight modeling was given by the use of input/output (I/O) and land use–transport interaction models, since these explained the interaction between trade, transport, and the economy (*6*). As behavioral modeling took up for passenger transport in the 1970s, the first mode choice models became available for freight as well.

The 1980s were characterized by an increased interest in network modeling and extended network models or hypernetwork models, explaining simultaneously trip generation, trade, modal split, and route choice (*7*).

TABLE 1 Key Policy Issues and Associated Modeling Needs

Policy Issues	Modeling Needs
Growth of freight: A doubling of freight flows by 2050 is expected worldwide. Within Europe, international flows are growing at twice the rate of domestic flows.	Forecasting international freight growth. Decoupling freight/economy. Sensitivity to cost changes.
Growing freight shares on the roads: As passenger traffic growth is slowing down and freight is moved by more and smaller trucks, freight is becoming more dominant on the streets.	Truck traffic behavior. Influence of freight intensities on car drivers.
Creation of seamless multimodal networks, new focus on motorways of the sea and inland waterways.	Linking sea and land transport models, EU multimodal networks.
Concerns about international competitiveness of the EU economy, two-way relation between worldwide networks and global trade. "Freight and the economy" discussion: What are costs and (mainly indirect) benefits of freight investments?	Develop suitable worldwide models and continental models. Improve relationship between SCGE and network models.
Pricing: Charging all modes of transport what they can bear (or what is fair, given external costs unaccounted for) is becoming reality. EU and member states have different attitudes and strategies toward pricing.	Situational response to cost changes (truck type, road type, time of day).
Logistic performance: The freight logistics sector is customizing its products and is creating complex, flexible networks by using advanced logistics concepts such as hybrid supply chains, collaborative networks, e-logistics (both business-to-consumer and business-to-business), and return logistics.	Differentiating between goods with different logistics backgrounds; making detailed statistics available.
Changes in vehicle types HGV/LGV: Light vehicle growth figures surpass other categories and appear to be more difficult to capture (in terms of both measurement and public policy).	Forecasting (causes and impacts of) choice of vehicle type.
Local environmental damage: New regulations on noise and emissions require more accurate prediction of freight impacts. New technology requires investments. Citizen involvement is required in freight planning.	Accuracy of forecasts and level of detail (type of traffic, spatial, temporal).
24-hour economy: To deal with congestion, firms are spreading production and logistics over day and night.	Explaining sprawl of flows to different periods of the day.
Security and safety: Traffic must be monitored for degree of risk depending on contents or origin of freight.	Modeling critical global movements: containers, oil, dangerous goods, food.
City distribution: As more stern policies are developed for city access and activities, freight requires new delivery concepts.	Forecasting of tours at urban level, time-of-day dependent.

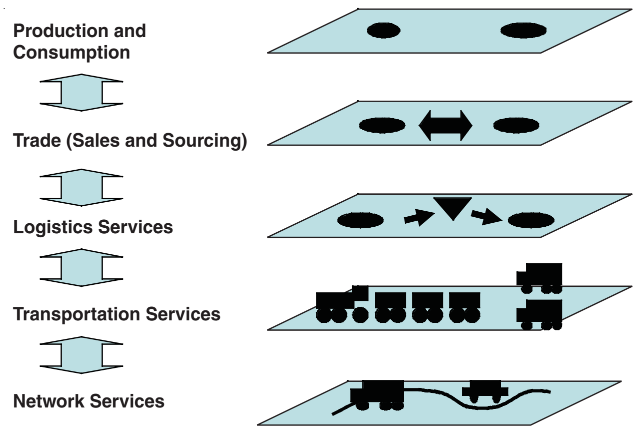

FIGURE 1 Conceptual framework of the freight transport system.

In the 1990s these models were extended by using a multicommodity context (*8*), improved probabilistic choice models, and inventory considerations (*9*). In the past decade freight network simulation has emerged (*10*, *11*). These models have taken up microsimulation and network modeling as approaches to describe the behavior of various agents in the system. Their advantage is that they can describe actors in detail, while their main challenge is their calibration and validation. A closely related new breed of freight models aims to describe agent behavior by including game theoretic considerations (*12*). These models focus on freight exchange markets and serve decision makers in both the private and the public world.

Table 2 summarizes these developments from the viewpoint of the system framework. The general trends are (*a*) increasingly integrative treatment of various decisions that firms make, or layers in the conceptual model, and (*b*) increasing detail of the behavioral content of models, down to the level of simulation in responses of individual firms.

The main developments in freight system models to be discussed in the next section are those indicated by the shaded cells in Table 2 and concern the following categories:

- Improving the representation of freight–economy forward linkages: In freight benefit–cost studies, an important impact to consider is the productivity growth associated with improvements in accessibility. These forward linkages within the economy require models treating the function of transportation in product markets. To this end, spatial economic models are being developed that integrate the first two levels of the framework, trade and production/consumption. The latest addition to this set of models is the spatial computable general equilibrium (SCGE) models, described below.
- Logistics behavior: Freight logistics models aim to describe explicitly the trade-offs between transport and inventory holding. They build a link between origin–destination (O-D) tables for production and consumption locations and O-D tables where warehouse locations are included. This is relevant since it determines (*a*) the spatial patterns for goods flows, changing the usage of infrastructure; (*b*) the costs of freight movements; and (*c*) the (local and global) economic impact of freight policies.

TABLE 2 Summary of Modeling Challenges and Techniques

Decision Problem	Typical Modeling Challenges	Typical Techniques Employed		
Production and consumption	Trip generation and facility location Freight–economy linkage Consumption patterns	LUTI (1970s) and SCGE (1990s) models	Trip generation models, I/O (1970s)	
			Gravity models, synthetic O-D models (1970s)	Agent-based simulation models (1990s)
Trade	International trade Value to volume conversion			
Logistics services	Inventory location Supply chain management considerations	Logistics choice models (1990s)		
Transportation services	Choice of mode Intermodal transport Light goods vehicles	Simple trip conversion factors (1970s), discrete choice (1990s)	Multimodal networks (1980s)	
Network and routing	Routing and congestion Tour planning City access	Network assignment (1980s), simulation (1990s)		

NOTE: LUTI = land use–transport interaction; SCGE = spatial computable general equilibrium.

- Freight trips and networks: In Europe research has been done in the past decade on multimodal network assignment for freight. These models operate at the EU and national levels and have various degrees of refinement, up to stochastic and multiuser-class models. At a more detailed level, however, the data challenge becomes daunting. Models that describe the choice of vehicle type at the scale of a city or region are virtually nonexistent. The main empirical challenges lie in disentangling light goods vehicles from heavier ones and service-sector from freight-only movements.

International Experiences in Three Areas of Innovation

In this section a brief account of the main research in modeling that has occurred in recent years in the areas mentioned above is given. The difficulties in the adoption of these innovations by their users and the challenges for further model development and implementation are described.

Freight–Economy Linkages

SCGE modeling has provided a new tool to model, in a consistent fashion, the first two layers of the system shown in Figure 1. From an economywide perspective, SCGE modeling is a commonly used tool. This model is based on a microeconomic general equilibrium framework that allows for substitution possibilities at the supply side (production) as well as the demand side (consumption) of the economy, via an endogenous price system. It takes account of intersectoral and interregional relationships in an economy and is hence a suitable tool for obtaining insight into economywide direct and indirect consequences of transport policies.

In Europe, the first example of such an SCGE model was the computable general equilibrium Europe model (CGEurope) model developed by Bröcker. He developed this model for 1,300 regions covering the entire European space (*13*). The main purpose of Bröcker's SCGE model is to quantify regional welfare effects of transport-related and financial–economic policies, such as the Trans-European Networks investments and transport pricing.

In the United Kingdom, as well as in the Netherlands, national economic research institutes have worked together in a research program on the economic effects of infrastructure, under the authority of the national government. On the basis of the findings and the work of Venables and Gasiorek (*14*), the Dutch SCGE model RAEM has been constructed and applied (*15*). Furthermore, European SCGE models have been developed in Denmark (the BROBISSE model) (*16*), Sweden (*17–19*), Norway (the PINGO model) (*20*), and Italy (*21*). Recently a Swedish initiative was launched to investigate the possibility of introducing SCGE modeling as part of the national freight model (*22*).

Outside Europe, SCGE models have recently been developed in the United States [e.g., by Löfgren and Robinson (*23*)], where relevant research has also been performed by Lakshmanan and Anderson (*24*). This work described conceptual and mathematical models that identify long-term efficiency effects of improvements in freight and passenger transport infrastructure. In Japan, SCGE models have been used (*25*, *26*) to analyze the potential impact on the Japanese economy of a major earthquake that damaged the high-speed rail network to Tokyo. Miyagi (*27*) has used an SCGE model to appraise the indirect economic impacts of a large expressway project.

A logical step in model development would be to connect such a model to a model of the rest of the freight transport system, replacing conventional I/O and gravity-type approaches. This step involves fitting the two parts of the system together in terms of representation of the transport sector, units of measurement, time scales, study area, spatial resolution, utility formulations, functional forms, and so forth. Examples of consistency issues that arise when SCGE and transport network models are linked are given by Tavasszy et al. (*28*). Clearly, the benefit of such an integrated treatment is the theoretical consistency gained within the freight modeling environment. A second, though related, benefit is an improved ability to assess indirect welfare effects of freight transport policy. Especially if logistics models are used, the economic impacts of changes in the logistics organization of shippers and carriers that occur as a response to changes in transport costs can be quantified. These effects are relevant in cost–benefit analysis of transport infrastructure improvements (*24*).

Since this is a relatively recent development, only a few applications have been made for transport policy purposes. The Dutch SCGE model was applied to several benefit–cost studies related to long-term port and rail development (*15*). The CGEurope model was used to advise the European Commission during the interim assessment of the EU white paper on the common transport policy. It provided new forecasts of sectoral and regional development in the scenario of decelerated development of the Trans-European Network. Despite the claim that these models are data hungry and tedious to calibrate, the fact that many countries have started to investigate these models is a promising sign. The first challenge to solve, however, relates to the preparation of national statistics (a detailed social accounting matrix or multiregional I/O would be sound) on which to base these models.

Logistics Behavior

The introduction of elements of logistics decision making in freight models took off in the early 1990s in the Netherlands. It has taken about a decade for these or similar approaches to become adopted elsewhere. Currently there are at least five logistics-based freight models under development in the world, four of which are in Europe. The most recent one is from the United States; in 2005, a proposal for the Los Angeles County freight model was presented (*29*).

The earliest reference to logistics models was made by Bergman (*30*), who proposed a more detailed spatial representation of logistics processes in freight logistics models. The Strategic Model for Integrated Logistics and Evaluations (SMILE) (*31*) is the first aggregate freight model developed to account for the routing of flows through distribution centers. The model enumerates alternative distribution channels, takes into account freight consolidation possibilities, and calculates the usage of these alternatives on the basis of a logit choice model. The model began operation in 1998 and has been used for many policy studies since then. The introduction of the model helped start a stream of new survey and modeling work in this area, both within the Netherlands and abroad.

At the Delft University of Technology, a model named GoodTrip (*32*) was developed. The model builds logistical chains by linking activities of consumers, supermarkets, hypermarkets, distribution centers, and producers. On the basis of consumer demand, the GoodTrip model calculates the volume in cubic meters per goods type in every zone. The goods flows in the logistical chain are determined by the spatial distribution of activities and the market shares of each activity type—consumer, supermarket, hypermarket, distribution center, and so forth. This attraction constraint calculation starts with consumers and ends with the producers or at the city borders. A vehicle-loading algorithm then assigns the goods flows to vehicles. A shortest-route algorithm assigns all tours of each transportation mode to the corresponding infrastructure networks. This results in logistical indicators, vehicle mileage, network loads, emissions, and finally energy use of urban freight distribution.

Another application that followed the SMILE development is the SLAM (Spatial Logistics Appended Module) (*33*), which was an EU-level spin-off. The model is appended to SCENES, the EU-level transport model. It obtains trade flows (in the form of a matrix containing flows between producing and consuming regions) as an input from SCENES and produces transport O-D matrices for the 200+ zone system in SCENES. These O-D tables incorporate alternative distribution chains. A chain is defined as the combination of distribution centers and transport relations for trade flows between producing and consuming regions. The second O-D table, the output of SLAM, is then fed back into a European freight network model, which uses the modified O-D table to determine modal split and routing of flows. This logistics module was adopted as part of the new standard EU transport modeling suite, TRANSTOOLS.

A slightly more advanced logistics module was proposed for the Swedish national freight model system SAMGODS (*34*). This proposal is now being implemented as a joint Norwegian–Swedish initiative in an even more refined form (*35*). In contrast to the above-described aggregate approaches, this model takes a mixed aggregate-disaggregate modeling approach. Here, aggregate data on trade flows between regions are distributed over pairs of individual firms on the basis of various firm attributes such as sectoral affiliation and size. The resulting disaggregate flows are then spread over different distribution channels (and, possibly, modes of transport) by using a microsimulation approach. In the final step these flows are aggregated again to form interregional transport flows.

In the United Kingdom, following the freight model review, parallel to the above models, the recommendation was to distinguish in the freight modeling framework between two types of spatial interactions: trade and transport interactions. Data describing interactions of the first type were termed production–consumption matrices, the second O-D matrices. The bridge between these matrices would be provided by a logistics module. The first practical result of this recommendation was a logistics model for the trans-Pennine corridor, presented recently at the European Transport Conference (*36*).

Freight Trips and Networks

At the national level, Belgium (*37*), the Netherlands, the United Kingdom, Finland, and Sweden (*38*) have developed hypernetwork approaches for freight network modeling. These network assignment models simultaneously treat mode and route choice; the Dutch model includes choice of vehicle type as well. In addition to the Belgian model, at least two other models—the Strategic European Multimodal Modeling and SCENES—use a multimodal network assignment approach. These models work largely on aggregate data.

Other countries usually treat mode choice and route choice separately. At the basis of mode choice models lie revealed preference (RP) and stated preference (SP) data sets. Recent SP or combined RP–SP work for freight mode choice was carried out in Italy (*39*), the United Kingdom (*40*), and the Netherlands. Network assignment has received relatively little attention, although multiple user class (MUC) assignment for road networks is becoming increasingly important, while truck shares on the road are growing. MUC assignment routines for freight were developed by Bliemer and Bovy (*41*) for road and by Lindveld et al. (*42*) for inland waterways.

The link between mode and route choice is a weak one. The usual approach uses fixed conversion factors from tonnes to vehicles, loading units, ships, or wagons, for each mode of transport and occasionally differentiated by sector or commodity group. Although some literature links shipment size and mode choice (*43*), even once shipment sizes and modes are known, it is difficult to develop models because of data difficulties. Empirical challenges are great since both services and product sectors generate freight movements and vans carry both passengers and freight. Another problematic area is the difficulty in modeling empty trips, since it is difficult to observe empty trips. A practical insight is given by Holguín-Veras and Thorson (*44*) on this matter. Wigan and Southworth (*45*) discuss the challenges in the broader area of modeling commercial, service, and light goods movements.

As to the general state of the art in urban goods modeling, local freight models currently are not much different from regional or global ones. Taniguchi and Thompson present an overview of available models (*46*). City logistics models involve either prescriptive/normative) approaches (for single firms or groups operating as one) or descriptive approaches, where the latter do not take into account the logistics processes behind freight traffic. For the most part the techniques used in descriptive models are direct demand models, which do not take into account explicitly the choice of mode or vehicle type. Some recent work in freight trip generation that takes into account various vehicle types was presented by Iding et al. (*47*) and Steinmeyer and Wagner (*48*).

Especially at the urban level, hardly any transport statistics are available to help in developing freight transport demand models. Where firm-level data are available, interesting possibilities open up, including detailed microsimulation (*49*). Groothedde (*11*) presents a simulation approach that makes use of a mix of public and private data to develop a detailed spatial database of consumer goods movements for purposes of microsimulation of logistics chains.

Concluding Remarks

The aim of this paper was to describe the major lines of freight demand model development that have developed outside the United States. An overview of the key policy issues and the associated modeling needs has been provided. Three major lines of model development have been identified, and the state of the art in these areas was described.

The conclusion is that a number of areas are still not covered sufficiently. In particular, there is insufficient knowledge at the network level of the many asymmetric interactions between freight and passenger traffic. With regard to the three lines of development highlighted in this paper, it is clear that this is a work in progress, despite the fact that the main bottlenecks for their introduction, as well as the early adopters, can already be identified.

A common thread through all three areas of innovation is the challenge to create new data about freight flows. The availability of advanced techniques for data gathering will influence modeling abilities in the future. New observation methods such as cameras and radar will allow a continuous monitoring of freight flows. In addition, new regulations concerning freight security will lead to a better accounting of freight passing certain checkpoints. Until these sources become available, however, a certain amount of creativity will be needed in combining aggregate and disaggregate data sources.

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DISCUSSION

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The paper "Freight Modeling: An Overview of International Experiences" is well structured. It describes the major lines and the international experience of freight modeling in Europe well. There are probably more experiences elsewhere, but most of the known experience in Europe comes from the Netherlands and Scandinavia.

The paper focuses on the relevant areas in freight model development:

- Freight–economy linkages,
- Logistics behavior, and
- Freight trips and networks.

The paper analyzes the importance of data as input to models. This was stressed in many other presentations at the conference.

The list of key issues could be extended by

- Direct benefits in cost–benefit analysis (i.e., the impact of improved infrastructure on transport time and reliability for freight transport),
- Regional and global environmental and climate impacts (i.e., the effect of higher or lower carbon dioxide

taxes and trade with emission rights for industry sectors and freight transport),

- Monitoring transport policy (i.e., transport quality as one of six goals in Swedish transport policy), and
- Multimodal corridor strategies including ports and terminals for combined road and rail transport.

A large gap between needs for infrastructure planning, transport policy, and so forth and the existing tools for freight transport is identified.

The remainder of this discussion focuses on the Swedish experience with national and regional freight models.

As in other countries, the need for better tools for forecasting and policy analysis was the driving force for the development of the national freight transport model system in Sweden. The Swedish Institute for Transport and Communications Analysis (SIKA) is responsible for planning methods and developing tools in the transport sector. SIKA develops passenger and freight transport forecast models and forecasts in cooperation with the National Road Administration, the Rail Administration, the Maritime Administration, and the Civil Aviation Authority. A single official transport forecast based on the same planning methods is used by all agencies, so it should be possible to compare road and rail investments with one another.

When national freight development was started in 2001, it was impossible to model all relevant reactions in the private sector with the existing freight model system. This is true for localization of companies, choice of shipment size, consolidation to make use of economies of scale, and so forth. The same development areas as in Tavasszy's paper were identified.

The "freight–economy linkage" and the development of economic forecasts were postponed. The focus was on understanding actual freight movements. Lack of knowledge of logistics behavior was also seen as the main drawback by neighboring Norway. Agencies from the two countries cooperate in the development of a logistics model. The Swedish National Road Administration also requires the assignment of all road traffic in one network.

The Swedish and Norwegian national freight models are traditionally based on the STAN system (an interactive graphic planning tool used for strategic planning of national and regional freight transportation developed by INRO consultants in Montreal). The models include generation, distribution, and multimodal assignment (in tons). To overcome the lack of logistics elements, the future freight model systems in Norway and Sweden consist of base production–wholesalers–consumption (PWC) matrices, a logistics model, and a network model. Normally, wholesalers receive large consignments from producers and send minor consignments to consumers. Some wholesalers perform the same type of services as warehouses and distribution centers.

The base PWC matrices contain zone-to-zone commodity flows. The Swedish PWC matrix consists of PC matrices, PW matrices, and WC matrices. It was decided at this stage not to overload the logistics model with the modeling of wholesale activities. The annual flows to and from the wholesalers are fixed (as part of the base matrix). The base PWC matrices are derived by using all available statistics. In Sweden the Commodity Flow Survey (CFS) is the main source. The development of the CFS, which is based on the same approach as the U.S. CFS, started in parallel with the model development.

The logistics model reads in PWC matrices (in tons) and delivers origin–destination matrices (O-D vehicle matrices) to the network model. The model is based on an "aggregate- disaggregate-aggregate" approach, which consists of three steps: (*a*) disaggregating from zone-to-zone to firm-to-firm flows, (*b*) minimization of transport and logistics costs per firm and year, and (*c*) aggregation of O-D flows by commodity in vehicles. The cost minimization step takes into account the trade-offs between inventory/order costs and transport costs and between high frequencies and economies of scale. Version 1 of the logistics model (from 2005–2006) is a normative cost minimization model to aggregate data. The planned disaggregated model estimation requires more detailed shipment data.

The network model initially produces distance, time, and cost matrices for the logistics model. The new approach requires additional detailed information about terminal or port characteristics (which goods can be handled), infrastructure restrictions (e.g., access to ports), and frequencies for different vehicle or vessel types.

Five regional road transport models are developed for the same regions as the passenger transport models. These models include both freight transport and service/craft transport. For freight transport, a model will be developed starting with the national vehicle O-D matrices. A hierarchic approach is also applied for the data collection. Counties, chambers of commerce, and so forth are offered the opportunity to extend the CFS sample by participating in their regions. For the non-freight transport correlations, data from a study in Stockholm County, where private and public work units were asked for their incoming and outgoing transport, will be applied to the whole of Sweden.

For more information about the development of the Swedish freight model, see www.sika-institute.se or contact inge.vierth@vti.se.