The DIDAM framework Disaggregated demand and assignment models for combined passengers and freight transport

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Abstract
The objective of this paper is to present the methodological developments in the DIDAM (Disaggregated demand and assignment models for combined passengers and freight transport) research project, which aims at advancing fundamental research in transportation modelling and analysis, using two complementary methodologies. The first is to develop a joint methodological approach for both freight and passenger transport, and the second is to base this common approach on the use of models that are as disaggregate and realistic as possible. Furthermore, the methods will be designed to cope with the important question of competition for infrastructure. The project is mainly organized around two themes. Each of them covers both freight and passengers aspects, in a manner which promotes collaborative work between the partners of the project. The first theme is concerned with disaggregate demand modelling issues, the second deals with innovative aspects of (joint) traffic assignment. Working at a fully disaggregate level is however not always easy. If such models are already available for passenger demand and traffic, disaggregate tools are still largely missing for freight transport. This is not only true at the operational level, but, more crucially, at the conceptual level. This is why our research program adopts, in this domain, a progressive approach that introduces disaggregation gradually into existing methods and models. This entails research in a full spectrum of issues, ranging from concepts definition (who are the actors, how can they be characterized ...) to validation exercises using available data sources.

Keywords
models, assignment, demand, transport, disaggregated, freight, framework, didam, passengers, combined

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KEYWORDS : multi-agents, transport, simulation, traffic assignment, disaggregated models

1. Introduction

The objective of this paper is to present the very first results of the DIDAM (Disaggregated demand and assignment models for combined passengers and freight transport) research project, which aims at proposing some advances in fundamental research in transportation modelling and analysis, using two complementary methodologies. The first is to develop a joint methodological approach for both freight and passenger transport, and the second is to base this common approach on the use of models that are as disaggregate and realistic as possible. Furthermore, the methods will be designed to cope with the important question of competition for infrastructure.

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The first part of the work is to model passenger transport and freight transport separately. The models must take account of time repartition of traffic. Then they will be combined in a whole single model so we can see the impact of freight transport on passenger transport and inversely.

To simulate freight transport flows, an approach based on multi-agents was chosen. This choice is motivated by the fact that agents are a well adapted concept to simulate negotiations and interactions between the different actors involved in a freight transportation chain.

On the other hand, the passengers transport flows are simulated using an approach inspired from the recent developments in the discrete choice modelling theory allowing us to simulate the route choice process of the agents. This methodology can also be seen as a multi-agent system.

2. State of the art

DIDAM is based on state-of-the-art concepts and methods. Central to the disaggregate approach is the "activity chain", that is a chain of actions/movements whose scheduling is performed by all the agents who are involved, facing the constraints imposed by infrastructure, time organization and prevailing regulations (such as land-use planning and fiscal (dis)incentives). Activity based research for individual transport demand has indeed long advocated that people do not move for the sake of it, but rather because of their desire to participate in successive activities taking place at different locations. The chain of the activities, with their locations and timings, is then considered as the determinant matrix from which individual trips result. The chain of successive handling operations and transportation modes in (a multi-modal) trip for freight follows the same paradigm. It is also the case of the (multi-modal) logistic chain in the same transport sector.
The modelling approaches which are developed exploit this common paradigm of a chain or sequence of "activities" (taken in a broad sense) subject to constrained decisions regarding their actual content (how many activities, of which nature?), their intrinsic characteristics (such as activity nature, mode of transport or localization) and their timing/scheduling. In such an approach, the various choice models are typically applied to “synthetic” populations of actors, which also need further specific research in how such populations can be generated.

Working at a fully disaggregate level is however not easy. If such models are already available for passenger demand and traffic, disaggregate tools are still largely missing for freight transport. This is not only true at the operational level, but, more crucially, at the conceptual level. This is why the research program adopts, in this domain, a progressive approach that introduces disaggregation gradually into existing methods and models. This entails research in a full spectrum of issues, ranging from concepts definition (who are the actors, how can they be characterized ...) to validation exercises using available data sources.

As stated earlier, multi-agents systems are used to model freight transport. There are a lot of different definitions of what an agent is. Therefore, it is common to define an agent by its properties. An agent

- is an entity able to act in its environment which it has a limited awareness;
- is able to communicate with other agents;
- is autonomous;
- and is able to take its own decisions.

All these characteristics make multi-agents systems a good way to simulate interactions or even negotiations between actors in a dynamic system. In the framework of this research, shippers will negotiate with transport firms.

Multi-agents systems are also more and more used in micro-simulation, focused on individual entities. In transport models, micro-simulations try to represent the behaviour of every single vehicle in contrast with macro-simulations that study aggregated traffic flows. There is not a worse or better type of simulation, each one having its advantages: micro-simulations are adapted to study interactions between actors within the traffic, but become too expensive for large-scale networks while macro-simulations, well adapted for large-scale networks, don’t take care about the interactions between vehicles.

The basic model that is implemented is based on the classical four step approach: Flow generation that determines the number of daily trips taking place in the region; Trip distribution that determines where every transport is coming from and where it is going to; Modal repartition that determines which transport mode is chosen by every actor of the traffic and Traffic assignment that determines the routes chosen to reach the destinations.

There is not a lot of scientific literature about the use of multi-agents in transport models. Multi-agents systems have however been used in a few studies. For example, El Hmam, et al. (2006) propose a hybrid model of traffic flow using multi-agents systems. The authors were able to combine a macroscopic and a microscopic model in a single integrated model. They used the Payne’s model (1971), a second order macroscopic model derived on the basis of car-following considerations taking into account the driver's reaction time which leads to a dynamic mean speed equation, to describe de sections of highways and multi-agents systems to simulate the behaviour of vehicles at discontinuities like roundabouts, crossroads…
Another example is the work of Sirikijpanichkul, *et al.* (2007), who used multi-agents to optimize the location of intermodal freight hubs. They used agents (hub owners, transport network infrastructure providers, hub users, and communities) with conflicting objectives that initiate negotiations that result in a location choice for a new intermodal freight hub. In their paper, Wisinee *et al.* (2007) proposed a micro-simulation model for urban freight movement incorporating the relationship between freight agents in supply chains where each of them tries to minimize the cost of each activity. Using their model, they analysed the urban freight movements in the Tokyo Metropolitan Area. In the work of Van Katwijk *et al.* (2004) a test bed for agent-based road traffic management is presented. It consists of three combined models: interaction model, intelligence model and world model, respectively used to model interactions between the agents, the artificial intelligence of the agents (with or without experience notion), and the traffic using Paramics, a microscopic traffic simulation package. By means of two scenarios, they show their test-bed offers a valuable aid for in-depth analysis in the field of traffic management. Another interesting source is the OVID research project (2002-2005), launched by the German Ministry of Research and Education. The goal of OVID is to analyse the impact of intelligent information systems in road transport. In this project the interaction between human agents, transport models, transport data sources and software agents to assess the benefits of better information and of de-central decision-making is modelled.

Multi-agents systems have been tackled from a more theoretical point of view by J. M. Vidal (2007). Although not focused on transport but more on games and AI, it contains a lot of interesting stuff, covering all the aspects that a multi-agent practitioner should be familiar with.

For passenger transport, the route choice process simulation of an individual between a given origin-destination pair can be dealt with the discrete choice modelling framework in an intuitively way. Indeed, the route choice problem can be rewritten as finding the path that would effectively be chosen by the individual amongst the set of all available paths. Detailed information about this kind of models can be found in Ben-Akiva and Lerman (1985) and Train (2003).

Unfortunately the discrete choice approach is endowed with two issues: firstly in order to calibrate the model, one need a dataset representing accurately the choice behaviour of the individual which is unavailable in our case and the set of possible path between an origin-destination pair possibly contains an infinite number of alternatives paths if the network contains loops.

The proposed model hereby described dealing with the aforementioned issues consist of a three-step process inspired by Frejinger’s paper (2007) detailing a random sampling of alternatives in a route choice context simulated by discrete choice models. The first step randomly built a set of feasible path between an origin-destination pair. These path are then associated with probabilities according to the network structure, the correlations between the alternative and the distance from the shortest path between the considered O/D pair. The last step finally randomly draws a path in the set previously built based on the computed path probabilities.
3. Stochastic Traffic Assignment

3.1. A first model

As stated previously, the set $U$ of all feasible paths between an origin-destination pair, denoted by $O-D$, can contains up to an infinite number of elements and becomes then irrelevant to practical computations. The main idea consists then of building a subset $P_n$ of $n$ paths between $O-D$ using a random walk algorithm.

Sub-paths and associated probabilities

The random sampling of $P_n$ relies on the concept of sub-paths corresponding to a sequence of links. A probability is associated with every sub-paths considered based on its distance to the shortest path. This probability is given by the double bounded Kumaraswamy distribution proposed by Kumaraswamy (1980) and defined as

$$F(x_s \mid \alpha, \beta) = 1 - (1 - x_s^{\alpha})^{\beta} \quad \forall x_s \in [0,1]$$

where $s$ is a sub-path between source node $u$ and sink node $v$ for the $OD$ pair, $\alpha$ and $\beta$ are the distribution’s shape parameters and $x_s$ is given by

$$x_s = \frac{SP(O,D)}{SP(O,u) + C(s) + SP(v,D)}$$

with $SP(a,b)$ denoting the cost of the shortest path between the node $a$ and $b$ and $C(s)$ the cost of $s$. As a result, $x_s$ can be seen as a measure of the distance of $s$ from the shortest path: $x_s = 1$ when $s$ is part of the shortest path, and the further it is from the shortest path, the more $x_s$ tends to 0. Note that any (generalized) cost function can be considered here.

Biased random walk algorithm

A biased random walk algorithm towards the shortest path presents at least two desirable properties. On one hand, as a result of its stochastic nature, the algorithm can potentially generate every feasible path. On the other hand, the probabilities associated with these paths can be easily and rapidly computed.

In order to build a path between $OD$, the proposed algorithm use as a starting point the node $O$ and then randomly choose a link starting from it based on the distribution previously described. Another link starting at the sink node of the first one is then selected and this iterative process is repeated until the destination $D$ is reached, i.e. a complete path has been generated.

Formally, if $s$ denotes a link, $i$ its source node, $j$ its sink node and $L_i$ the set of all outgoings links from $i$ then the algorithm first compute the distance of every link inside $L_i$ from the shortest path given by

$$x_s = \frac{SP(O,D)}{SP(O,u) + C(s) + SP(v,D)}$$
\[ x_s = \frac{SP(i, D)}{C(s) + SP(j, D)} \quad \forall s \in L, \]

and the associated probability is given by

\[ p(x_s \mid L_t, \alpha, \beta) = \frac{F(x_s \mid \alpha, \beta)}{\sum_{i \in L_t} F(x_i \mid \alpha, \beta)}. \]

A link is then randomly drawn based on the computed probabilities, and the algorithm moves to the sink node of the chosen link.

This algorithm can be repeated \( n \) times in order to get the desired number of sample paths between the \( OD \) pair. Note that these \( n \) paths are not necessarily distinct due to, again, the stochastic nature of the method.

One can easily see that depending on the shape parameters of the Kumaraswamy distribution, this random walk algorithm tends to be more or less biased towards the shortest path. Indeed, if \( \alpha = 0 \) and \( \beta = 1 \) then the algorithm becomes a simple random walk algorithm, but the more \( \alpha \) grows, the more the generated paths tends to be closer to the shortest path.

**Traffic Assignment**

Once all the paths have been generated between an \( O-D \) pair, it is possible to compute for all of them the probability \( q \) of being generated which, for a given path \( J \), is done by

\[ q(J) = \frac{q'(J)}{\sum_{J'} q'(L)}, \]

where

\[ q'(J) = \prod_{s \in J} p(s \mid \alpha, \beta) \]

correspond to the product of the selection probabilities of its constituents links.

The closer a path is to the shortest one, the higher its selection probability becomes, thus this approach can also be seen as an importance sampling procedure. Consequently, the procedure will only assign significant probabilities to reasonable paths, i.e. not too far from the shortest one. In that sense, this methodology is quite similar to the one developed by Dial (1971) but overcome the need to enumerate all the reasonable paths.

Suppose that the set of sampled path contains \( n \) elements. These elements are associated with a probability distribution and consequently the traffic assignment for an individual between the \( OD \) pair is done by randomly selecting a generated path based on the probability distribution.

The proposed algorithm is being implemented and tested on the well known Sioux Falls road network. The first experiments tend to demonstrate that this stochastic traffic assignment’s
behaviour highly relies on the cost function, the parameters of the Kumaraswamy distribution and the sample size.

3.2. Futures developments

At this point of the project, all the generated path are assumed to be independently distributed, which is not true as, for example, two paths sharing some links must share some correlation. Consequently the next step will be to introduce a correlation structure amongst the alternatives paths. This issue will be treated by investigating the use of the Path-Size strategy developed in the discrete choice context in order to modify the path’s selection probability by the individual.

Another interesting way to investigate would be the introduction of the inertia of individual’s choice behaviour, i.e. if an individual chose a path between a given origin-destination pair one day, then he is likely to choose the same path again the next day. As previously, this can be done by modifying the definition of the probabilities associated with the paths.

4. Multi-agent based freight model

As outlined earlier, the final objective of the DIDAM project is to combine passengers and freight in a single model framework. The data used at the freight side will essentially based on an origin-destination matrices at the NUTS-5 level for the 10 NST-R chapters produced on the basis of recent NUTS2 data made available in the framework of the Transtools European project and on two surveys: Entreprise and ECHO, which will be briefly presented later. At this early stage of the project, only regional Walloon road transport is considered.

The quantities to be transported between the NUTS-5 regions within the Walloon Region are spread over the firms in these regions using the Entreprises database. This database, handled by “La Direction des Réseaux d'Entreprises” of the Walloon Region, contains about 4 800 companies located in Wallonia. It includes firms grouped in five sectors, including 433 transport companies. These databases is based on a written questionnaire survey, and validated by direct telephone calls. The information is continuously updated, so that a new version of the database is published every 6 months. The ECHO survey will be used later in the project in order to take shipment sizes into account.

The questionnaires are in particular focused on the shippers’ industrial and logistical characteristics and on the physical, economical and spatial characteristics of their consignments and transport chains (P. Hanappe et al (1989), M. Guilbault et al (2006)). The survey gathered detailed data on four types of statistical populations: establishments, consignments, transport operators/service providers, and route segments. In ECHO, several consignments had been sampled for exhaustive tracking from its departure from the shipper’s place till the delivery at the consignee indicated by the shipper. Tracking the consignment allows reconstitution of the whole chain: both the physical chain – considered as a succession of route segments and transport modes – and the organizational chain – considered as a succession of operators/providers. The consignment, which is the scope of this survey, is seldom used as indicator in transport models. The taking into account for it in our work is certainly an interesting improvement.
4.1. First milestone

One of the first objectives in this part of the project was to write a piece of software able to generate time dependant OD matrices, using agents. This program simulates negotiations between shippers and transport firms. The carriers answer positively to the demand for transport emitted by the shippers when they are able to fulfil them (availability of enough trucks). Both the shippers and the carriers are represented by agents, each having their own characteristics. For example, shipper-agents have a location, an activity sector, a size… Carriers have a stock of available trucks (that vary dynamically) located somewhere, an activity sector (according to the kind of trucks)…

The characteristics of the agents are taken from the Entreprises database. These include the number of employees of each plant. At this stage of our work, the number of employees is used to spread the quantities of goods emitted/received by each NUTS5 region over the several firms located in it.

The aim of this step is to generate a time dependant OD matrix from a traditional matrix. At this stage, and in order to test the program, it was decided to spread the demand over time using a simple normal distribution. This will be refined later. For now, every firm has been given a demand frequency calculated in function of the size of the firm and the total quantity of freight leaving the region per year.

Thus, for the time being, the program takes an OD matrix as input, distributes the flow over the different shipper-agents in function of their size, location and type. These agents generate demands for transport services, and carriers-agents answer to these calls. The program then finally writes every transport in a new time dependant OD matrix.

4.2. First results

Using JADE (Java Agent DEvelopment framework), a first negotiation simulation was developed. JADE (F. Bellifemine, et al. (2007)) is a middleware for the development of applications that enables developers to implement and deploy multi-agent systems.

In the program, the agents are autonomous and take their own decisions according to what they know about their environment. Shipper-agents make a public call for transport services and the carrier-agents able to fulfil the demand propose their price for a transport service. The shipper-agent that receives multiple answers chooses the cheapest offer and conceals a contract with the related carrier. In this explanatory phase, every shipper-agent makes a public call at a given fixed frequency (different for each). It is worthwhile to note that the output matrix contains the different trips generated by a transport task, including the empty trips needed to collect the freight at the shipper's address and the empty return trip the carrier's location. This could be assimilated to the output of the first two steps (generation and distribution) of the classical four stages model.

As only road transport was considered for now, no particular attention was given to modal-split yet. However, each carrier has different kind of trucks to transport the different goods, and the repartition between the different types of trucks is already implemented. Finally, the produced OD matrices are assigned using the NODUS software (2006), a G.I.S. (Geographic
In a next step, the ECHO 2004 statistics will be used to generate consignment sets. ECHO 2004 is a questionnaire survey, conducted by the French national research institute (INRETS) in order to have a better understanding of shippers transport practices. It covers 3 000 establishments with more than 10 employees of the sectors of industry, wholesale trade and warehousing. The consignment is the originality of this survey. Generally, a consignment generates a provision of transport service and a vehicle movement. It is thus directly related to produced vehicle-kilometres on the networks.

Furthermore, for the time being, only random shipment frequencies were given to each shipper. This frequency is proportional to the quantity of employees of each enterprise and to the quantity of goods that leave the area. This is not realistic and must be improved. For example, seasonality should be taken into account for some transports. The distribution of the demand over a day needs also more attention, as demands for transport are not uniformly over the whole day. This aspect must be treated explicitly if the model has to be able to take the capacity constraints (congestion) of the road networks into.

Another limitation of the currently implemented solution is that all the enterprise “wakes up and goes back to sleep” one after each other: once awaken, a shipper sends a single demand message to every carriers and waits for answers from them. While waiting for answers, nothing happens. In such an approach, the carriers doesn’t really have the opportunity to put in place a strategy designed to maximize their profit, as they don’t know at which time they will receive a call from a next shipper. Carriers can only handle a single contract at a time, so they are unable to wait for a more profitable deal, if one becomes available. The current workaround is to wake up the shippers sooner, so they will wait for answers while other shippers will wake up and make new demands. As a consequence, the carriers have the opportunity to choose the best contracts for them and real negotiations will take place, having also the opportunity to accept several demands if it is possible to reduce empty trips (cabotage).

Finally, for now, the shippers always choose the cheapest offer. Indeed, the only thing that is taken in account in the negotiations is the direct transportation costs of the transport, that depends on the location of the carrier. It would be nice to take time slots into account. For instance, a shipper could ask to have its goods transported at a defined time. In such a case, the carrier that is able to propose a service at the wanted time will be promoted. More rules such as punctuality, frequency of the demand ... could be introduced in the multi-agent model, making it more and more realistic.

5. Project perspectives

The DIDAM project is quite ambitious because it will combine passenger and freight transport in one single model. It will permit to assess the competition between these two sources of traffic and the impact of infrastructure modification on it. This model could have impacts at two levels:
- From a microscopic point of view, it can help shippers to optimize the management of their production and carriers to choose the transportation tasks they accept.

- From a macroscopic point of view, it can drive some policy decisions and forecast impacts on the global traffic.

Finally, the model will help to assess the current locations of transport companies, as it can simulate the transport activities generated by the different firms located in the considered area.

The next step that will be taken from the passengers transport point of view will be the development of a representative synthetic population for Belgium which will be used as an input for a discrete choice model to simulate the choice of daily activity chains which will lead to the generation of a dynamic origin destination matrix. The traffic assignment model needs also to be refined in order to take account of the freight transport impact on the travel behaviour of the individuals.

References


