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A distributed Agent-Based Freight Simulation for Large Scale Road Network

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Abstract

The expansion of ports in urban areas creates challenges for both long and short terms planning of transport logistics. This is compounded by increasing demand of goods, services and mobility in the urban environment which in turn affects traffic congestion. In this respect, the UK Government and the private sector face a joint challenge in seeking new solutions for a sensible trade-off of social, economic and environmental aspects through development of new infrastructures, to new 'Uber' type planning solution that proactively guides the hauliers to make decisions based on the latest status of the ports, the congestion on the routes and delays in pick-up and drop-off points. This requires solving complex large-scale freight-urban traffic optimization problems capable of handling live streams of heterogeneous information. In this paper, we present a hybrid agent-based distributed traffic simulation capable of handling a large road network. The system can model individual behaviours such as that of a typical driver, as well as centrally optimized decisions typical in transport planning. We discuss how this simulation platform is used to evaluate the social, economic and environmental benefits for an end-to-end multi-modal journey planning for freight transport in the UK.

Keywords

Agent-based simulation, traffic simulation, freight transport, transport planning

1. Introduction

In the UK a study[1] by INRIX and the centre for Economics and Business Research predicts that the annual cost of congestion will rise 63 percent by 2030 to reach £21 billion. The study also found that the cumulative cost of congestion between 2013 and 2030 will be a staggering £307 billion. The expansion of ports in urban areas with high population density also creates challenges regarding both long and short terms planning in transport logistics. The area around port of Dover and the channel tunnel between Dover and Calais is a case in point. In 2016, disruptions in Calais caused traffic jams of up to 14 hrs with queues in excess of 12 miles. To mitigate this problem, the government implemented Operations Stack[2] where up to 3000 lorries can be parked on part of the M20 highway with plans for a £250 million lorry park that was subsequently scrapped due to resident protests.

Trucks moving in and out of urban port areas are the biggest contributors to the congestion issue and one of the main reasons why congestion arises is that they all pile up to the port at the same time, either to pick up loads when a ship arrives or to drop off loads prior to the ship's departure. In larger container ports, slotting of trucks to pick-up containers may provide some smoothing of the traffic but it is still the case that multiple trucks are slotted at the same time and changes in slotting time due to either port or truck delays still result in pile-ups and congestions. Any solution to this issue must involve information sharing on delays, arrival and departure times and collaboration among the various entities involved in the movement of goods (ports, hauliers, freight forwarders, truck drivers).

Supply chain management focuses on the research of resilience, flexibility, and robustness across the managerial, information, communication and material flow dimensions. Several techniques, models, and tools have been developed in order to anticipate and minimize the negative effects of exogenous uncertainty and disruption such as congestion. The growth of complex inter-correlations between the actors and the flows in the global supply chains networks has pushed to seek new forms of collaboration rather than competition. For example,

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[1] http://inrix.com/press-releases/traffic-congestion-to-cost-the-uk-economy-more-than-300-billion-over-the-next-16-years

[2] https://en.wikipedia.org/wiki/Operation_Stack

digitalization of the information flow along the entire supply chain has generated new forms of collaboration based on the information sharing. Agents that are usually in competition one to another have the possibility to get mutual advantages from a cooperative information platform, getting access to a set of information previously distributed in a heterogeneous fashion.

The CAPITALS (Collaborative and AdaPtive Integrated Transport Across Land and Sea) project follows this line of thought. It seeks to develop a number of innovative applications and services that are uniquely based on more adaptive, integrated end-to-end freight transport information, thus ensuring more efficient use of available capacity with enhanced resilience to disruptions. When deployed and used in a collaborative fashion, it will also reduce congestion by better synchronization of the trips by either eliminating unnecessarily waiting times or better planning of the waiting times. If adopted by the industry, it has the potential to contribute to reduce the need for operations stack in the UK.

The aim of this paper is to introduce the first attempt to develop a framework for implementing agent-based simulations in the freight-transport sector, by facilitating the development, testing, and evaluation of complex collaborative systems, in this specific case CAPITAL.

The paper is organized as follows. An overview of the CAPITALS solution is given in the next section. Section 3 gives the details of the framework for an agent-based high performance road and sea freight simulator. Section 4 describes how the simulation platform is used to showcase the benefits of the CAPITALS system and Section 5 concludes with some future development plans.

2. Overview of the CAPITALS project

CAPITALS (Collaborative and AdaPtive Integrated Transport Across Land and Sea) is a commercially driven project, funded by Innovate UK, that is led by Avanti Communications Ltd. While rooted in the industry, it is supported by a number of partners including industry experts, cutting-edge IT solution providers and academia. Projects members include AIMES, ContainerPort Ltd, Freight Transport Association Ltd, General Lighthouse Authorities, NPL, Route Monkey Ltd, Voyage Control Ltd, Terrafix Ltd, Transport Catapult, Zipabout Ltd, Hull City Council, Liverpool City Council and the Logistics Institute at the University of Hull.

CAPITALS addresses the important issue of the lack of an effective end-to-end journey coordination system for freight transport which results in inefficiency and higher cost on the maritime-to-port and land-to-port legs of journeys. These arise from unsynchronised ETA/ETD between vessels and lorries, missed berthing windows, congestion due to inappropriate routeing, missed loading/unloading windows, wasted driver hours/fuel, empty running and penalties from missed deliveries.

The project aims to develop an innovative and scalable multi-modal transport applications and services to support synchronisation of information flow throughout the supply chain for more

efficient, greener, safer movement of goods and people across end-to-end land/sea. CAPITALS will reduce the costs/consequences of these inefficiencies by developing applications and services that are uniquely based on more adaptive, integrated end-to-end freight transport information, thus ensuring more efficient and innovative use of available capacity with enhanced resilience to disruptions.

The CAPITALS project consists in the development of 1) a multi-modal journey planner 2) a dynamic vehicle/vessel booking system, 3) e-Navigation services for more accurate vessel ETA and port synchronisation and 4) an agent-based modelling tool that can handle large scale road/sea freight simulation models to perform what-if scenarios and showcase the benefits of the CAPITALS systems when fully deployed.

At the heart of the CAPITALS solutions is a distributed database that gets and compiles live information streams from ports, hauliers and other stakeholders involved in the movement of freight for an end-to-end journey. The solution starts at the planning level where a goods owner has a transportation need. S/he will use the Multi-modal Journey Planner to plan and execute the transport. Once a transportation order is placed, a driver will be assigned to pick-up the load and deliver it to a location that may be a port or a customer. In case of a port, it may be that a slot must be booked for the delivery. The Dynamic Vehicle/Vessel Booking system will handle this. In any case, there will be both an estimated time for pick-up and an estimated time for the drop-off. Delays and changes will be communicated to the driver of the truck through an App on his smartphone. Route information will be dynamically updated based on predictive intelligence of the status of the transport network. The system will be capable of adapting to changes in circumstance across sea, road and rail transport modes, thus allowing logistics operators (freight forwarders, independent lorry drivers, rail and vessel operators) to optimize freight transport movement services (using metrics such as time, price, carbon emissions), maximizing asset usage and reducing empty running. Smart real-time scheduling and routing algorithms to/from port and destination are to be incorporated to optimize use of time and resources as well as reduce possibility of guiding vehicles through inappropriate routes and ensure compliance with local authority restrictions.

For example, if there is an incident, accident or congestion on a road segment, a driver equipped with the CAPITALS App will be able to send an alert to the central database and the system will compute new routes for all CAPITALS drivers affected by this segment. If there are delays at the port, the system will alert drivers not to drive to the port and to possibly schedule another job or stop at a location that will not contribute to congestion near the urban port areas. The driver will later be alerted as to when s/he can resume driving.

The CAPITALS system will achieve its full potential as more and more people use the system. The full benefits resulting from the CAPITALS system can be tested and evaluated by using the proposed framework. This allows generating a simulated environment in which the system

can be trained to respond to negative exogenous events. An overview of the main aspects that can be manipulated by using the framework is in the next section together with the scenarios to be simulated.

3. A New Framework for agent-based transport freight simulation

One of the most important aspects to take in consideration when analysing freight transport is its impact on private and public transport and vice versa. For this reason, the framework provides several modules to insert also these subjects in the same model and study how they affect each other.

A module provides the implementation of the physical level in which all the agents (trucks, ships, cars, buses, etc.) interact with each other. This provides a hybrid microscopic-mesoscopic event-based traffic simulator designed for parallel processing. These two models are connected and synchronized during the simulation in order to exploit their combined potentialities in one large road networks analysis. Other several modules are provided to capture all the important aspects of the operations of traffic network including: dynamic traffic assignment (Peeta 2001), network equilibrium models (Boyce 2007), car-following models (Kayvan 2015) (Brackstone 1999), multi-lanes traffic flows models, etc.

Besides the physical level, there is a management level. This level is provided for both freight and non-freight transport. Focusing on freight transport, a package provides the tools that allow recreating one or more transport management systems and connect them to groups of agents. A set of optimization models to achieve the best performance of the transport fleet is provided by default but customizations and external connections to other optimization models and tools are possible.

Figure 1 shows the client-server architecture of the framework that can be executed on High Performance Computers to run the simulation. The user can create new simulations using a GUI on the client-side, accessing a large set of data coming from several private and public external sources on a road network. These data allow the user to generate an accurate simulation environment in which different complex scenarios can be analysed.

Defining a scenario means e.g. defining the source and the demand points for freight, number of trucks per hauliers and their locations, the possible triggers for events occurrences (such ship arrival or accidents) and the background traffic and congestion distributions on different segments of the road network. Rules can be defined to compute new routes and processes added with activities, times and delays at pick-up and drop points.

Once defined, a significant step before the simulation starts involves the conversion of the non-distributed structures to distributed versions in order to be executed in a parallel processing environment.

When an instance of the simulation is ended, all the distributed data are centralized and saved in the local database for further analysis. A dashboard consisting of a set of standardised metrics (e.g. number of trucks used, miles driven loaded or empty, number of customer served, etc.) allows the user to see the main simulation results at a glance. A set of analytical tools is provided to the user in order to further navigate and analyse the results in an unstructured way.

The simulation output can be visualised through a 3D environment designed to allow the visualisation of several hundred thousands of individual agents. It can be played back in normal or fast mode and the user can choose to see several detailed areas of the simulation in different 'windows' at the same time.

Figure 1: Label
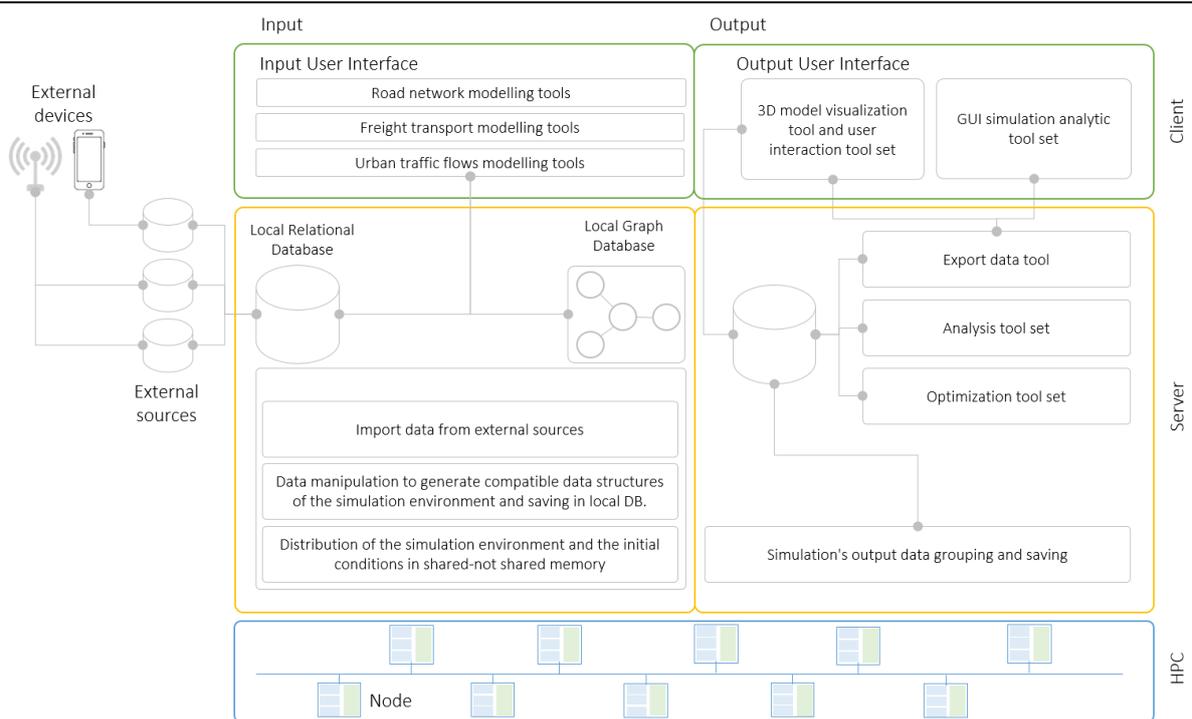
4. Integration of the CAPITALS system scenarios in the East Yorkshire scenario

East Yorkshire is an area in Northern England with a population of 335,000, covering 930 sq mi. The largest city in the area is Kingston upon Hull. A few miles from the city, at the confluence of the River Hull and the Humber Estuary, there is the Port of Hull. This is the UK's leading softwood timber port and is the focus of the Humber's burgeoning renewable energy sector.[3] In the last decades, the main arteries connecting the port to the highway network have experienced increasing congestion due to a greater number of trucks used to pick up and delivery goods at the port. This has led the local authorities to seek new solutions to this problem through the development of new infrastructures but also through better management of the freight flows to the port. The CAPITALS system looks promising in this respect. A small-scale trial has been implemented to test the communication hardware, but in order to prove its benefits on a larger scale, the CAPITALS system has been recreated by using the tools provided by the proposed framework and integrated into the East Yorkshire scenario. This scenario provides an estimation of the private and public transport flows thanks to the equilibrium traffic model provided as a default package in the framework. Since this is not the topic of this article, below we will focus only on the integration of the CAPITALS system in the scenario and the tests carried out to prove its benefits.

4.1 CAPITALS system components

The CAPITALS system includes two main components. The first is the jobs scheduler. This consists of an optimization model that takes into consideration the vehicle capacity constraints, pick-up and delivery time windows, drivers constraints, current traffic conditions, and several others in order to minimize a combination of factors as costs, CO_2 emissions, delays, etc. Once a set of transportation orders is placed in the CAPITALS cloud-based platform, the jobs scheduler assigns the drivers a list of pick up/delivery locations that may be a port, a customer, a warehouse, etc. Several events can prompt the CAPITALS system to re-plan the schedule of pick-ups and deliveries already allocated to a single truck in a previous solution. This is necessary in order to adapt the solution to new conditions. These events are most of the times unpredictable and they are the main cause of inefficiency of the solution if not properly treated. The second is the slot-booking system. This consists of an optimization model that assigns a time window to each pick-up/delivery at the port. The objective is to minimize traffic

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[3] http://www.abports.co.uk/Our_Locations/Humber/Hull/

congestion and waiting times. Even in this case, the system needs to take into account possible re-optimizations in order to mitigate possible inconvenient.

For instance, if a truck is late for a pick-up slot, the CAPITALS system will inform the port services and request a new slot. Similarly, if port activities are delayed and pickup slots are no longer the optimal, the CAPITALS system will alert the driver so that the latter can either park somewhere and not come to the port increasing the congestion or consider doing some other value-added activities instead of waiting. Both of these two components are integrated into the simulation as a set of events inserted in the discrete event scheduler of the simulation. The behaviour of a large set of entities adopting the CAPITALS system can be simulated using the proposed framework. The simulation also gives the opportunity to study this complex system under several aspects and different points of view (customers, port, hauliers, shippers).

4.2 CAPITALS scenarios

The agents connected with the CAPITALS system for all the scenarios implemented are 200 hauliers, 2 ships, and the port of Hull. Each ship transports 250 containers that have to be picked up at the port and delivered to different points into the considered area. Moreover, a set of orders are generated from the customers in the area, the orders consider only single container transportation. Some of these orders involve the transportation of containers among customers inland, some others involve maritime transport and the containers have to be transported to the port in order to be loaded on a ship. The total number of orders generated during the simulation is 210. The simulated time is 24 hours, regardless of the fulfiller of all the orders. Two are the main scenarios used to test how CAPITALS reacts in unpredictable situations and how this has an impact on the agents connected to the system but also on the external agents (private and public vehicles) in terms of costs, CO_2 emissions, and delays.

In the first scenario, an incident is simulated on the A63, one of the main highways to arrive at the port. All the trucks that have a pick-up or delivery in the schedule, based on the last output of the jobs scheduler, are potentially affected by this event. A set of information is collected for a new run of the jobs scheduler (current traffic delays, trucks potentially affected by the event and the list of their future orders, etc.). The new jobs scheduler output is distributed to all the agents for which the order list is changed. Accordingly, even the slot-booking system is adapted using the new output of the jobs scheduler and the estimated arrival time of the trucks at the port.

In the second scenario, one of the ships is delayed by 3 hours. All the containers (orders) transported by the ship will be available on a different time. Even in this case, a new solution for both jobs scheduler and the slot-booking system is required to adapt the solution to the new conditions.

5. Conclusions and future developments

This paper presents an overview of a new framework to implement distributed agent-based simulations in the freight transport sector. A real case using the aforementioned framework is shown. Besides some of well-known traffic models for microscopic and mesoscopic levels provided as packages in the framework, the development focused on a set of tools to study management systems in the transport freight field. These type of systems need to be tested in a dynamic environment and with a considerably large number of users before being deployed on the market. This makes simulation the best tool to evaluate the benefits that these systems can bring. Although the framework has been already used with success in a real case, several improvements still have to be made to make it easily extensible and maintainable. To this end, emphasis will be paid to enhance the tools that help the users to design their customized management systems e.g. fleet management system and slot-booking system.

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