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Agent-Based Simulation for Supply Chain Transport Corridors

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***Abstract*—**Supply chains are the backbone of trade and commerce. Their logistics use different transport corridors on regular basis for operational purpose. The international supply chain transport corridors include different infrastructure elements (e.g. weighbridge, package handling equipments, border clearance authorities, and so on). This paper presents the use of multi-agent systems (MAS) to model and simulate some aspects of transportation corridors, and in particular the area of weighbridge resource optimization for operational profit. An underlying multi-agent model provides a means of modeling the relationships among stakeholders in order to enable coordination in a transport corridor environment. Simulations of the costs of container unloading, reloading, and waiting time for queuing up tracks have been carried out using data sets. Results of the simulation provide the potential guidance in making decisions about optimal service resource allocation in a trade corridor.

***Keywords*—**Multi-agent systems, simulation, supply chain, transport corridor, weighbridge.

I. Introduction

SUPPLY chains are important part of every economy and every business [21]. Supply chain is generally formed as a network of suppliers, factories, warehouses, distribution centers, and retailers through which raw materials are acquired, transformed, and delivered to customers. More specifically, supply chain management (SCM) uses operational practices which ensure efficient integration of suppliers and customers (composed of retail outlets, distribution warehouse, manufacturer, and transporter) so merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to optimize system wide costs while producing value for money to its customers. Such systems need to link diverse organizations for day-to-day operational planning purpose.

In particular supply chains transportation planning is a complex task, as few operations managers have suitable tools to assist their understanding of how various strategy formulation influence this difficult, socio-technical problem (e.g. corridor infrastructure development, freight management, reduction of transportation carbon footprint, and so on), and in particular transport corridor's smooth operation related issues.

A transport corridor is a route that connects two geographical locations (i.e. regions, cities), using road, rail or sea connection. Transport corridors and their impact on supply chain performance are getting much more attention by academics and practitioners in recent years. In particular, with the increase of containerized maritime freight and the setting of more efficient (time and cost-wise) freight distribution and transportation systems. In this way, monitoring of transport corridors has been playing an important role in the business world.

In addition, transport logistic part of supply chains move containerized items where transport conditions (e.g. temperature, special storage conditions for perishables goods) and transportation time are important requirements. In this process, corridor management team (e.g. customs officials, weighbridge facility managers, traffic managers), as shown in Fig. 1, needs to collaborate with supply chain transportation companies. Border points in transport corridors can often become overwhelmed by large numbers of simultaneously arriving containerized freights and it creates huge operational problems for the corridor management teams. Moreover, limited resources in the check points, inappropriate infrastructure, ineffective operational procedures, and human error can create delays for supply chain transportation companies. This in turn has got a knock on effect in supply chain operational performance.

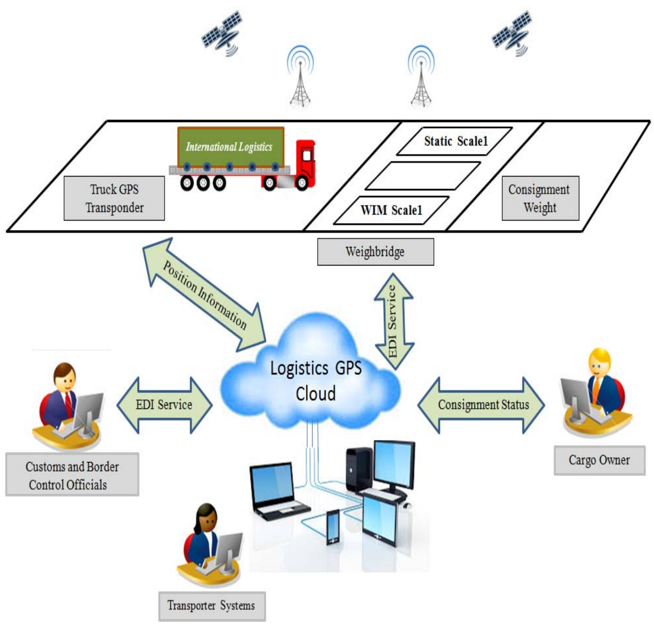

Fig. 1 Agents involved in corridor management

Problems such as delays during transportation require prompt corrective action for a supply chain management team.

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Due to the high complexity of the present day t ransportation requirements – a variety of computerized support systems have been developed [6], [20], [7]. These are mostly academic research applications, which provide an overview and control of the state of a subset of nodes in the c hain of transportation applications. The main disadvantage of these systems is their inability to serve all poss ible eventualities. Due to the involvement of multiple parties and its dynamic complexity, transportation chain operational performance can only be appropriately understood and assessed by employing simulation methods. Simulation has a long standing tradition in the dynamic analysis of manufacturing and transportation problems.

Moreover, corridor management systems consist of different types of intelligent and autonomous entities, such as supply chain logistics trucks, truck driver, custom officials, weighbridge, package handling equipments, traffic management systems, and other border control authorities, which are located over a wid e geographical area and interact with each other to achieve flexible supply chain transportation. In this way, multi-agent systems (MAS) provide an appropriate mechanism to model and simulate corridor traffic management since it offers a personalized way to abstract and describe every autonomous entity on the individual level. In a multi-agent corridor management system, each i ndividual interacting entity is modeled as an agent. Agents are capable of work cooperatively with each other. Multi agent systems have been widely used to inve stigate traffic-related problems, such as rou te guidance [1], urban traffic management and control [29], collaborative driving [11], railway traffic control [4], combined rail and road transportation systems [10].

The main objective of this paper is to present a simulation and analysis approach for the performance of a h ypothetical transport corridor. The si mulation approach includes the modeling of transportation cross-border agencies and overloading control cent ers of logistic operations. Managing such complex activity is heavily dependent on automation through combining advanced techno logies, such as so ftware agent technology [8], [13], [15], [17], [19], [30]; service oriented computing [22]; Internet of Things [28], [16]; and so on. In this paper, a multi-agent-based simulation architecture is employed as a means to understand cross-border operational practice. This study tries to understand weighbridge congestion related issues and sched uling to supp ort more effective supply chain management. Supply chain transportation companies can utilities the results of such simulations to both to manage day-to-day operations and improve their operational strategies by analyzing alternatives in simulation experiments.

The remainder of the paper is organized as follows. Section II introduces the basic operational practice in international corridor management and t he relevant issues. Section III presents a multi-agent framework, the description of individual agents, and agent-based supply chain simulation literature survey. Section IV provides a b usiness scenario to demonstrate some functionality of the simulation experiment, which is based on finite queuing theory and resource allocation related issues. Finally, Section V discusses concluding remarks and outlines areas for future work.

II. International Corridor Management

Globalization has brought about a dra matic increase in cross-border international trade. As a result there has been an equally important focus on trade and regulatory business processes conducted at the border to ensure they are optimized and the time required for trade-related procedures is reduced, where appropriate. In this way, it allows countries and firms to improve efficiency and reliability of their supply chains. In its transportation journey, a container goes through corridors; customs agencies manage the crossin g of international borders. In crossing such c orridors, several inspections are carried out to both the containers and th e transporting vehicles. The main aim of check weighing is to enforce laws concerning weight limits. These exist to r educe damage to road and bridges, to protect the environment, to improve road safety and to ensure fair competition. Weighbridges are used through which trucks are directed to drive through. Weight-in-motion (WIM) scales are often use; where traffic signal either direct the container to a static scale o r to proceed on to the highway. If a vehicle is found to be overloaded, it goes through regulatory sanction processes. Often, at this situation, container transporter is then asked for an alternative transportation means to offload the excess goods and charged a financial penalty. As a consequence, corridor connectivity is being hampered by serious delays.

In addition, corridor connectivity is affected by: (i) lack of customs clearance coordination and consequently excessive dwell times; (ii) incompatible infrastructure, poor service reliability; (iii) inadequate coordination, and congestion; and (v) poor access to information and communication technology (ICT) infrastructure.

Analysis of the literature on trade corridor management reveals that t raditional mathematical modeling techniques dominate. At the same time, however, new approaches start to appear. Intelligent agent technologies and multi-agent systems in particular appear to be one of the most promising directions for the de velopment of decision-support systems in transport corridor management.

III. Multi Agent Framework

An agent is an encapsulated computer system that is situated in some environment, and that is capable of flexible, autonomous action in that environment in o rder to meet its design objectives [30].

In recent years, agent t echnologies have been u sed in logistics and transportation research. Intelligent agent represent the organizations within the supply chain transportation area, and m odel their logistics functions, processes, expertise, and interactions with other organisations. Due to t he similarity in ch aracteristics between intelligent agents and organisations, agent technology is an ap propriate choice for modelling organisations in the supply chain and transportation research [24]. Some agents related research

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simulate users involved in traffic; others are by means of transport entities (trucks, trains, planes, ships), or elements of the traffic infrastructure [32]. Multi-agent systems offer such useful features as parallelism, robustness and scalability. They are highly usable in domains and problems where centralised approaches meet their limits. Multi-agent based approaches are well suited for domains, which require the integration and interaction of multiple source of knowledge, the resolution of interest and goal conflicts or time bounded processing of data [31]. Therefore, these approaches allow a distributed modelling and distribtion of tasks to be solved within the processing of international transportion corridors.

Kaim and Lenar [14] desc ribe an approach to create t he multi-agent system (MAS) for simulating transport corridors. Their approach is used to c hoose the most efficient way to send goods along a corridor. JASON language is used in implementation of this system. The soc ial aspects of agents are emphasized in this approach. The system combines the '*prometheus methodology'* [25] and JASON language [3], but is not fully implemented.

An agent based approach has been used in [12] to analyze the transaction costs and organisational structures in a transport corridor and to evaluate or det ermine choices for using or bui lding corridors. In contrast, the ap proach in t his paper focuses on improving the operating efficiency of existing corridors, and in particular at bot tleneck points such as weigbbridges.

A. Supply Chain Simulation Literature Survey

Many researchers have been probing into solutions for enterprise integration and s ome reached the conclusion that the agent technology provides a nat ural way to realize enterprise integration. In project ADE [18], agents have been used to model supply chains using delegation-based event handling. In AGENT-OPT, Chan and Lee [5] , use a case-based model modification scheme that can generate modified formulation from the semantically specified requirements. Project Co-OPERATE[2] employs an integrated infrastructure design on top of legacy transaction systems with XML being chosen for interoperation between heterogeneous systems. In DISPOWEB [9], a supply web is designed using agents to facilitate autonomous decision making for production planning and logistics. In project MaBE, [15], employ a holonic agent approach for manufacturing and logistics service planning. MASCOT [27] is a reconfigurable and multi-level agent-based environment, employing a b lackboard architecture and mixed-initiative decision support. Finally, HOLOS [26] is an o pen, agile and reconfigurable dynamic scheduling system based on generic agent architecture.

Compared to a mathematical modelling approach, agent-based simulation of supply chains has advantages such as:

- Based on logic rules (states and transitions).
- Captures the dynamics of the simulated system.
- Centralized or decentralized approaches can be used.
- Provides a realistic Supply Chain representation
- Efficient optimization strategies need to b e developed amongst the agents.

With the above justifications of MAS application in transportation problem, the next section describes the individual agents functionality considered in the framework.

The use o f multi-agent systems has been used to simulate cross border logistic conainers journey consisting of intelligent agents (e.g. network traffic manager, road traffic coordinator, cross border facility manager, queuing facilitator, logistic centre scheduler, and truck driver) capable of autonomously co-operating with each other. A brief description of this agent community is shown in Table I.

The agents interactions are is shown in Fig. 2. Ag ents cannot operate autonomously unless they have an understanding of the environment they are in. Information of environment, the role individual agent play in its community, the main objective individual agent pursuing, the actions it is empowered to execute, the information individual agent seeking, the service it provide are essential elements in order to model these agents and established communication within it community.

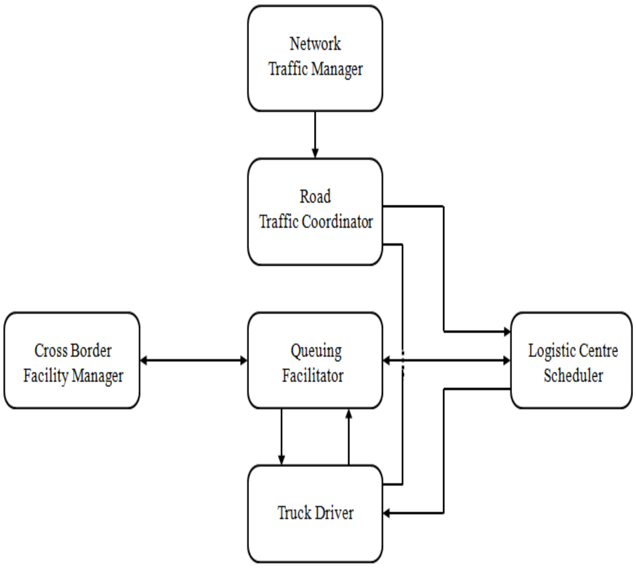

Fig. 2 Software agents in corridor management

As per Fig. 2, t he different agents exchange information about the state of the t ransport corridor in order to cooperatively improve key performance parameters such as costs and transit time. For different scenarios, the simulation can reveal optimal or near optimal values for different parameters, as described by a case study in the following section.

IV. Business Scenario

In this experiment the overall efficiency and expected net profit of a hypothetical corridor services have been computed for the wai ting time of logistic trucks outside a weighbridge, by using a specific queuing model [23]. Five lifting machineries of identical size and capacity are considered for handling consignment packages to do the unloading and reloading operations in t he particular corridor. There are

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variations of time taken for unloading the consignment trucks due to the r equirement of individual package handling policy for health and safety reasons. On the basis of the past experience, uploading time is found to follow negative exponential distribution with an average of 10 hours between getting emptied. When a truck gets empty it has to be filled by a loader. Although the capacity of the trucks is the same, the time taken to fill the trucks varies due to the different combinations and types of loads. Fig. 3 shows how the various agents submit data to the simulation model.

TABLE I
BRIEF DESCRIPTION OF AGENTS

Specific Agent	Description
Network Traffic Manager	Making the best use of existing corridor infrastructure; follows different legislative (e.g. Road Traffic Regulation, Highways Act, Road Network Works Act); and can take contingency actions.
Road Traffic Coordinator	Assisting day-to-day operational management of corridor works and liaison with the network traffic manager.
Cross Border Facility Manager	One of the key issue facing facility manager today is the challenge of delivering consistent services across boundaries – whether city-to-city, region-to-region, or country-to-country.
Queuing Facilitator	Queuing facilitators offer help to logistic truck drivers; and liaison with 'cross border facility manager' and 'logistic centre scheduler' agents.
Logistic Centre Scheduler	A logistic centre or depot is a facility dedicated to logistical operations. A logistics centre might be a warehouse, freight forward, or contengency resource depot schedular main purpose is to service optimization, plan and delivery of logistic operations.
Truck Driver	Truck driver collect consignments from source station to deliver it to destination.

TABLE II
DECISIVE DECISION STEPS

Step	Step Description				
STEP-1	T = Average service time, U = Average running time, and X = Service factor. Then using the following equation – X = T / (T + U) = 0.200				
STEP-II	For N = 5, and X = 0. 200 – th e values of M (servic e channels), D (probability that if a unit calls for service, it will have to wait), and F (efficiency factor) have been tabulated as follows:				
		M	D	F	
		3	0.028	0.998	
		2	0.194	0.976	
		1	0.689	0.801	
STEP-III	The decision making guidance will be as follows:				
	1.	Number of pay-loaders	3	2	1
	2.	Overall efficiency of system (F)	0.998	0.976	0.801
	3.	N (1 – X)	4.00	4.00	4.00
	4.	Average number of service running per hour: J = NF(1 - X)	3.992	3.904	3.204
	5.	Expected profits @ 1000 per hour in local currency.	3,992	3,904	3,204
	6.	Loading cost @ 100 per hour per pay-loader	300	200	100
	7.	Expected net profits per hour	3,692	3,704	3,104

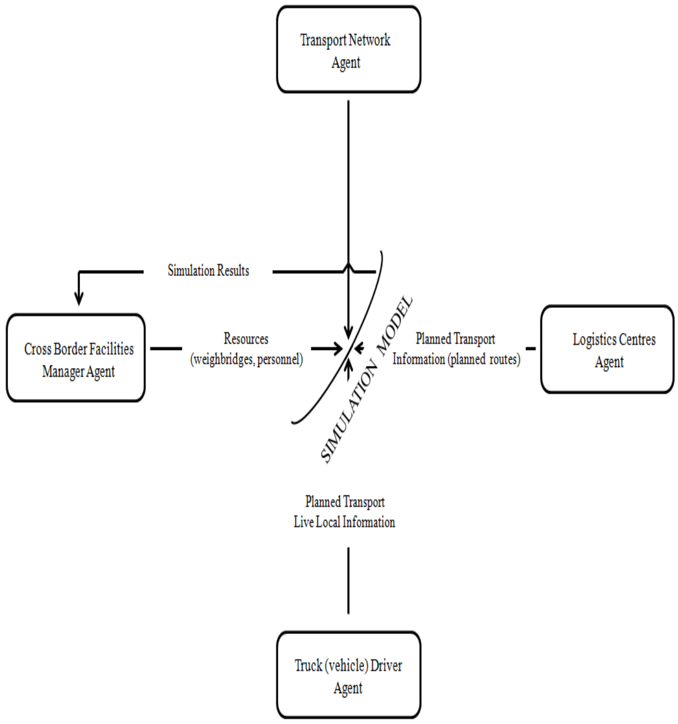

Fig. 3 Interaction between agents and the simulation model

The time for filling the t ruck also was found to follow negative exponential distribution with an average of 2.5 hours. The corridor authority hires the pay-loaders at a cost of 100 units per hour in l ocal currency, irrespective of whether it is operated or not. If the co rridor service pr ovision has to be stopped due to its truck getting empty it costs 1000 units per hour in l ocal currency, in terms of loss o f profits. A set o f decisive steps, as shown in Table II, needs to follow in order to come to a final solution.

V. CONCLUSIONS

A multi-agent simulation model for supply chain transport corridor management has been described in this paper. An overview of basic concept of supply ch ain management, and in particular transportation related issues in corridor management purpose are presented. The main concept of using multi-agent model for corridor management is described, and a queuing theory based business simulation case is proposed.

Work on the cost and efficiency of corridors, in the greater context of supply chain management point of view is currently ongoing. Real word international corridor transportation data need to be co llected in order to evaluate any pattern within simulation and real-world operation. In addition, cooperation between software agents of the involved parties (authorities, logistics companies) can further support optimization across the whole tran sportation chain. Particu larly, the e fficiency of internal messaging mechanism among relevant agents needs to be investigated in future work.

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