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Fleet management enterprise systems and traffic control synergies: a literature review and research agenda

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Abstract

Synergies between fleet management enterprise systems and traffic control systems for information sharing and collaborative planning can contribute to significant improvements to operational efficiency, safety and environmental impact. This paper provides a synthesis of the extant body of research on synergies between fleet management and traffic control systems identifying five key topics in prior research and suggesting research directions. The findings are based on a systematic literature review and topic modelling with the use of natural language processing (Latent Dirichlet Allocation). The five topics identified are related to: hazardous goods transportation, environment and emissions, position tracking and navigation technologies, traffic management and fleet operations´ optimization. The two most frequent topics link to social responsibility (minimizing accidents during hazardous goods transportation and minimizing environmental impact) indicating the relevance of this area of research to sustainability. Despite the strong potential for synergies between intelligent transportation systems and enterprise fleet management systems, the review identified a paucity of research on the coordination between real-time fleet management and traffic control measures (e.g. ramp metering, route guidance, variable speed limits and signal control).

Keywords: fleet management system; traffic control; intelligent transportation systems; topic modelling; Latent Dirichlet Allocation.

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1. Introduction

Enterprises face new challenges including pressures for becoming more socially responsible while increasing efficiency. Enterprise Information Systems have been rapidly evolving to help them respond to pressures in a constant interaction between business requirements, requirements set by authorities, technological potentialities and organizational capabilities. A key trend has been to build more collaborative information systems, i.e. information systems that can support collaborative work and can exchange information across organizations [1]. This can be achieved within "ecosystems" within which different technical components evolve [2]. Ensuring information flows to and from external entities has proven beneficial; enterprises that rely on closed systems are clearly restricted in terms of business choices and overall efficiency [3]. Interestingly, most advancements and research on collaborative enterprise information systems has focused on information sharing upstream and downstream in value chains (e.g. across suppliers and clients) while information sharing and collaboration across levels (for instance, between enterprises and central coordinating bodies) is relatively underdeveloped.

Transportation of goods is one of the most important collaboration-intensive activities. Land-based transportation is an important part of the overall transport sector, conducted over road networks, which are under the jurisdiction of local and central government agencies operating Traffic Control Centers (TCCs). Enterprises in the transportation and logistics business conduct long and short haul transportation operations utilizing these networks, with fleets of vehicles of various sizes and classes. These enterprises typically use Fleet Management Information Systems to track and manage vehicles. A recent study [4] identified a wide variety of information technology-enabled capabilities for such systems: transportation information capabilities including freight transportation data exchange, vehicle driving and road traffic data, vehicle communications; transportation infrastructure capabilities including congestion identification, traffic and infrastructure monitoring; transportation management capabilities including fleet management, crew composition, freight booking, vehicle scheduling and routing; transportation monitoring capabilities such as real-time cargo monitoring, freight tracking and tracing, real-time vehicle speed and position monitoring and transportation operations capabilities including parking booking, vehicle driving automation, platoon formation. Linking Fleet Management Systems and systems used by TCCs to support information sharing and collaborative planning can contribute to significant improvements for both road traffic and fleet management.

Over the past years, the potential for synergies between enterprise Fleet Management Systems and traffic control systems has been identified. Enterprises have started exploring possibilities to leverage traffic information and coordinate with TCCs while, TCCs have started sourcing information from Fleet Management Systems to better manage road traffic. The ability to share information and coordinate has been greatly enhanced by technological advances. Organizations are recognizing that partnerships based on information sharing can bring benefits and are worth cultivating. These benefits relate to operational efficiency, safety and environmental impact contributing to sustainable development.

In this paper we report the findings from a comprehensive literature review guided by the following question: "Which topics related to synergies between Fleet Management Systems and traffic control systems have been addressed in previous research literature?". Our contribution is twofold. First, we extract and present five key topics that cover the whole domain. Second, drawing from the findings of the review we identify gaps in the literature and suggest directions for further research. It is argued that although extant research provides evidence for the feasibility and value of synergies between Fleet Management Systems and traffic control systems, these synergies have not been fully realized yet. The findings and suggestions are based on a multimethod approach that includes a systematic literature review, topic modelling with the use of natural language processing (Latent Dirichlet Allocation), and qualitative document analysis.

The remainder of the paper is organized as follows. Section 2 provides the background for synergies between Fleet Management Systems and traffic control pointing to the expected benefits from collaboration and information sharing between Enterprises and TCCs. Section 3 presents the method used for identifying and analyzing related literature. The results of the literature analysis are included in the section that follows. The paper ends by discussing the results and suggesting research directions.

2. Background: Synergies between Information Systems for Fleet Management and Traffic Control

Enterprises operate their fleets to satisfy customer demand with a desired level of service, whilst minimizing their costs and complying with regulations and policies related to transportation. In general, the maximization of profit is achieved by minimizing the costs of fuel, crews, drivers, warehousing and vehicle usage subject to a number of operational and regulatory constraints. Social responsibility and environmental impact are becoming also increasingly important affecting decision making. Fleet Management Systems address a variety of problems that need to be solved in very shorts amount of time if not in real time. These problems include the scheduling of goods´ loading and unloading within specific time windows, the scheduling of crews and drivers, booking of parking slots, dispatch of orders and individual vehicle route guidance.

Congestion identification, real time network traffic state estimation and prediction of future states and travel times are necessary for modern Fleet Management Systems to schedule crews and vehicles, prioritize orders and apply vehicle route guidance. A significant volume of information relevant for these tasks is available in TCC systems. For example, route guidance for fleet vehicles with the aim to minimize fuel consumption and emissions requires real-time traffic state information transmitted by TCCs. TCCs are responsible for the operation, maintenance and control of a range of cyber-physical systems distributed over the road network. They are tasked with the problem of sensing, surveying, monitoring, and actively interfering with the traffic flow. TCCs control road networks equipped with sensors and control effectors such as traffic lights and variable message signs. Fig. 1 provides an overview of how a TCC operates.

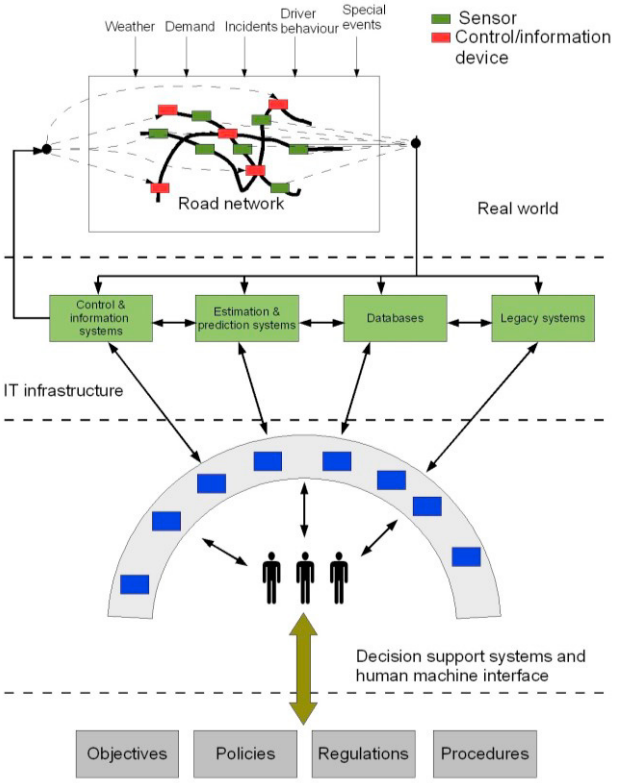

Fig. 1: schematic of a Traffic Control Center (TCC).

Traffic management is a challenging task, encompassing diverse hardware and software systems, which is complicated by the often chaotic nature of human behavior, the diverse needs generating individual trips, the constraints imposed by regulations (for instance, related to emissions), and the objectives pursued (for instance, delay

minimization). Currently, the most common architecture for TCCs is that of a centralized control structure, allowing room for decentralized operations under strong supervision [5]. Some of these decentralized operations are performed by enterprises that manage their fleets using Fleet Management Systems that receive information about the prevailing traffic conditions. Enterprises can set optimal routes and speed trajectories of individual vehicles exerting direct control over their fleets, however, the control of each individual vehicle is subject to the constraints imposed by the road traffic conditions and the TCC's control actions. Closer coordination can be achieved by establishing communication links and a corresponding information infrastructure, between the Fleet Management System and the TCC with the explicit purpose of informing road network authorities about each vehicle's mission parameters. Mission parameters include vehicle type features, destinations to be visited, cargo load transported (and its condition), desired speed profiles over space and time and time windows that need to be observed for making deliveries. Effectively through such a communication link, TCCs would be informed about the demand profile generated by the fleets. The communication of detailed demand profiles to the TCC can contribute to more predictable and less volatile traffic conditions in the road network. Predictability and relative stability of traffic conditions are very important for fleet management, especially for routing based on time-dependent travel times [6].

From a fleet management perspective, close coordination with TCCs can be very beneficial increasing operations´ predictability and supporting socially responsible fleet operations (e.g. related to environmental concerns). This coordination is also of interest for TCCs. Close coordination can prevent the uncontrolled entry of relatively slow-moving vehicles (e.g. trucks) in the road network. Slow moving vehicles can lower average speeds, create congestion and increase emissions of pollutants. Coordination can be facilitated by designing control strategies that take under consideration the traffic flow vehicle class mix, i.e. the composition of traffic with respect to different vehicle classes such as passenger cars, vans, trucks etc. It is well known that the traffic flow dynamics are heavily influenced by the vehicular flow class mix [7]. Having accurate and timely information available about the expected composition of traffic in the road network improves the efficiency and flexibility of traffic control strategies. With the advent of digitally equipped and network-connected vehicles and vehicle automation, a treasure cove of information gradually becomes available. Large quantities of data can be collected from the vehicles, processed in a TCC and subsequently information can be transmitted back to them, offering significant new possibilities to TCCs to positively interfere with traffic in real time, improving at the same time the efficiency of fleet management operations.

3. Method

A systematic literature review [8, 9] was performed to provide a comprehensive synthesis and an interpretation of the body of research on the interplay between fleet management and traffic control, to organize this prior research under key topics and to substantiate the need for targeted research in the domain. We used Kitchenham's (2004) guidelines for systematic literature reviews [10] in combination with recent methodological guidelines on natural language processing for topic modelling in literature reviews by Asmussen and Møller [11, 12]. Extant research on synergies between Fleet Management and traffic control systems is broad and fragmented and a wide variety of relevant terms is used in the literature. We aimed for comprehensive coverage including many alternative terms in our inquiry. The use of language processing for topic modelling was adopted in order to expedite the review process. Topic modelling allowed us to group related papers into topics, enabling an overview of the main research topics of the paper corpus identified. Furthermore, this method has the added advantage of providing replicability and transparency, as other researchers can follow the same process to verify the results or run the analysis when more papers have been published [12]. The combination of Kitchenham and Asmussen and Møller guidelines led to a review process with three main parts: (1) planning, (2) implementation, and (3) reporting.

During planning we carefully developed our search strategy which entailed dividing the key focal concepts into parts and including alternative terms to optimize the searches. For this, we used authors´ expertise in this research domain to identify alternatives. We performed the literature search in Scopus which includes all major journal and conference outlets in Enterprise Information Systems and Transportation research. Scopus also provides advanced search functionalities which made the search more efficient. We used Boolean operators to create a search string that includes appropriate synonyms and also, wildcards for lemmatising words when needed. For instance, for the words transport, transportation and transporting, transport is the lemma and in the search string we included the term:

“transport*”. We also used Boolean operators to exclude terms that relate to literature not relevant to road vehicle fleet management (for instance, we excluded papers that relate to maritime, rail and air transportation). The search was performed in May 2022 and yielded 199 articles. Table 1 provides an overview of the literature search performed.

Table 1. Literature Search.

Key concepts	Alternative terms	Database	Inclusion criteria	Exclusion Criteria
Fleet Management	"freight management" "goods transport*" "long haul logistics" "road cargo"	Scopus	The search terms should appear in the article´s title, abstract, keywords. Peer Reviewed articles Articles in English.	Literature not relevant to road vehicle fleet management in the context of Enterprise Information Systems: excluded articles that include: "maritime" OR "airplane" OR "rail*" OR "airport*" OR "taxi" OR "bus" OR "bicycle" OR "canal"
Traffic control	"route guidance" "ramp metering" "variable speed limits" "traffic authority" "road network operat*"			

During review implementation we performed topic modelling using Latent Dirichlet Allocation (LDA) which is a statistical approach used in natural language processing for topic discovery [13, 14]. LDA has been applied extensively for topic modelling within fields such as software engineering, political science, computational social science, medical and linguistic sciences [14, 15]. It is used to discover topics in a collection of documents and classify each individual document in terms of how "relevant" it is to each of the discovered topics. Each topic is a set of words frequently occurring together suggesting a shared theme. LDA identifies such sets of words based on the co-occurrence of individual words. Assigning meaningful titles to each individual topic is up to the analyst, and requires knowledge in the domain. To perform the LDA analysis of the articles identified through our literature search we used jsLDA, an open-access in-browser topic modeling tool which implements LDA in javascript. The tool was developed by David Mimno (Cornell University) and can be accessed at: https://mimno.infosci.cornell.edu/jsLDA/. Mimno’s jsLDA was chosen because it is a mature LDA implementation which has been available for almost a decade (since 2013) and used in multiple research publications that apply topic modelling. The source is transparent (provided in Github) and the tool includes functionality for loading and curating any text corpus, training LDA models to extract topics, sorting documents based on topics and representing graphically the interrelations among extracted topics. The algorithm was run for different numbers of topics. It was found that the best interpretable number of topics was five. This number led to topics that are they are quite different from each other. The number of training iterations was 800 as the topic structure was stabilized by then.

To report the findings, the authors assigned a title to each of the topics identified by considering the documents that are strongly connected to a topic, along with the words associated with the topic. Furthermore, the articles were labelled according to their dominant topics. In topic modelling, each document is assumed to include multiple topics to varying degrees (0–100%). Hence, each document is not necessarily assigned to a single topic but can be labelled with more than one if needed (i.e. if more than one topic is found to be above a probability threshold for negligible contribution).

4. Findings

An overview of the research topics within the literature corpus analyzed is provided in the paragraphs that follow. All five topics identified are about information systems that leverage synergies between traffic control and fleet management but each of the topics has a special focus. Specifically, the topics focus on: a) hazardous goods transportation, b) environment and emissions, c) technologies for position tracking and navigation, d) traffic management, e) optimizing fleet operations. Among these topics, the one focused on hazardous goods transportation was significantly more frequent than the other four (Fig. 2).

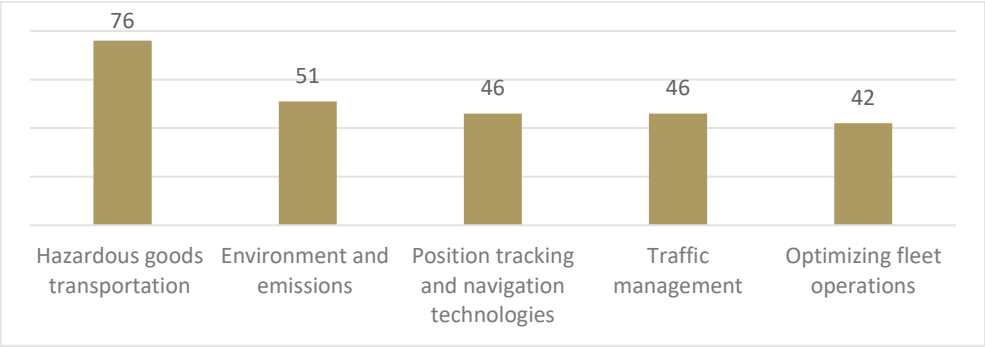

Fig. 2. The five topics identified and their frequency within the literature corpus.

Topic 1: Hazardous goods transportation

The transportation of hazardous goods emerged as a major topic from the literature analysis. The words associated with this topic are: dangerous; freight; road; goods; transport; traffic; network; monitoring. Papers on this topic are concerned with accidents such as explosions and leakages, identifying contributing factors for accidents during hazardous good transport or contributing to the design of incidence response programs [16]. Hazardous traffic tracking in coordination with TCCs is identified as an important element [17]. For instance, researchers investigated risk prevention systems for dangerous chemical transportation pointing to the importance of information exchange between TCC authorities and other agencies [18]. Other researchers [19] have considered risk assessment for trucks carrying dangerous goods and developed models that can be used by decision making authorities and transportation companies. The collaboration between traffic authorities and fleet managers is a *de facto* procedure when it comes to transporting hazardous goods. Hence, the two-way information link between fleet management systems and TCC systems is a natural area of synergies between traffic control and fleet management.

Topic 2: Environment and emissions

The second most frequent topic identified in the literature is concerned with environmental issues and gas emissions. The words associated with this topic are: environmental; communication; traffic; vehicles; transportation; management; control; fleet. Road transportation is one of the major contributors of CO_2, CO, NOx, SOx, particulate matter and other pollutant emissions and minimizing such emissions is a key concern. Hence, it is no surprise that there has been research from an environmental perspective on synergies between fleet management and traffic control. TCCs have a mandate to monitor and protect the environment from the impact of traffic. Logistics firms and other enterprises managing fleets find themselves increasingly under pressure to improve their environmental profile and to find ways of "greening" their operations as much as possible. TCCs monitor congestion and noise levels [20] over large stretches of highways and are implementing intervention measures to reduce the environmental impact of traffic. Technologies such as platooning [21] can reduce fuel consumption and increase throughput by integrating traffic control architectures with systems coordinating fleets. A key concern within this topic is the development of sustainable transportation using technologies and business models encompassing coordination strategies at various levels [22].

Topic 3: Position tracking and navigation technologies

Another cross-cutting topic related to synergies between Traffic Control and Fleet Management that was identified in the literature is technology-specific and relates to position tracking and navigation technologies. The words associated with this topic are: GPS; positioning; satellite; GNSS; navigation; tracking; location; detection. This was expected as position tracking and navigation technologies are key enablers for both traffic control and fleet management. The GPS, GLONASS, GALILEO global navigational systems have emerged as important technologies along with tracking algorithms. These are mature technologies used by both TCC systems and fleet management systems [23-25]. Research on this topic substantiates the technical feasibility of introducing communication links and information exchanges between the two types of systems.

Topic 4: Traffic management

Within the literature analyzed, a topic that indicates a focus on traffic management was identified. This topic is included in papers that do touch upon both fleet management and traffic control from the TCC perspective. The words associated with this topic are: transport; road; public; urban; planning; requirements; cities; drive. Research has pointed to the synergistic potential between commercial organizations and public authorities leading to win-win situations improving mobility [26] with the deployment of information exchange platforms. From the TCC side, this potential is realized by the frequent (real-time if possible) and accurate updating of the demand generated by the various fleets operating in the network [27] for increasing the relevance and efficiency of the control strategies used. A different group of articles investigates the problem of demand management and how information exchange between enterprises that manage fleets and TCCs can inform measures such as road pricing, time-based access control or maximum speed zones [28].

Topic 5: Optimizing fleet operations

Finally, the fifth topic indicates a focus on optimizing fleet operations. This topic is included in papers that do touch upon both fleet management and traffic control from the perspective of fleet management operations conducted by enterprises. The words associated with this topic are: driving; fleet; management; vehicle; dynamic; algorithm; FCD; routing; algorithms. Within this body of literature, data exchange systems are proposed for pooling together information obtained from fleet vehicles acting as Floating Car Data (FCD) probes [29], enabling the use of traffic conditions to feed fleet management solutions. Dynamic fleet management is also an important part of this topic, with papers discussing solutions that take advantage of available real-time traffic information from Vehicle-to-Infrastructure (V2I) communications systems for managing live vehicle fleets and assessing their environmental impact [30]. Traffic simulation packages are used as a tool for evaluating algorithms solving the Vehicle Routing Problem with variable and time-dependent travel time updates [31]. The combination of real-time or near real-time data about traffic conditions with optimization algorithms is at the core of this topic.

5. Discussion and Conclusion

An interesting observation is that the two most frequent topics identified relate to social responsibility (minimizing accidents during hazardous goods transportation and minimizing environmental impact). This indicates the importance of ensuring synergies between fleet management and traffic control and its relevance for sustainability. These synergies can enhance road infrastructures´ resilience and adaptive capacity, protect the environment and improve urban conditions (United Nations´ sustainability goals 9, 11, 13). Sustainability improvements are a strong motive for closer collaboration between logistics firms and TCCs. Many environmentally cautious enterprises aim at reducing emissions, whereas TCCs have by mandate responsibility for reducing the environmental impact of traffic.

The findings from the literature analysis indicate the technical feasibility of sharing information and coordinating between fleet management systems and TCC systems. However, although there has been an understanding from the broader transportation community of the potential benefits of such collaborations, the initiatives reported in the literature remain at the conceptual and planning level. Research on how to bridge each actor's operations and how to design coordination schemes, detailing the information content, the pooling of resources and corresponding algorithms remain one-sided. Fleet Management Systems have evolved to a level of sophistication that allows the consumption of information available from TCCs. Further research is needed to find ways for TCCs to exploit the information that can become available from Fleet Management Systems for the purpose of traffic control design. The literature review conducted has revealed limited work on the synergies that can be achieved from the coordination of traffic control measures such as ramp metering, route guidance, variable speed limits and intersection signal control with real-time fleet management decision making. This is an important finding, since it outlines a gap in the research on the intersection of intelligent transportation systems with enterprise fleet management systems.

The work reported in this paper provides a proof-of-concept for literature reviews supported by natural language processing. The use of natural language processing yielded very good results. For instance, it brought to our attention the latent stream of research on hazardous goods transportation which was extracted from the text by the algorithm.

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