

An Advanced Transportation System Based on Internet of Things

Sotiris P. Gayialis¹, Grigoris D. Konstantakopoulos²,
Evripidis P. Kechagias³ Georgios A. Papadopoulos⁴

National Technical University of Athens,
School of Mechanical Engineering,
Sector of Industrial Management and Operational Research,
9, Iroon Polytechniou Str.,
Athens 15780, Greece
sotga@central.ntua.gr¹, gkonopoulos@mail.ntua.gr²,
eurikechagias@mail.ntua.gr³, gpapado@mail.ntua.gr⁴,

Abstract

The improvement and reinforcement of logistics and freight distribution in cities can be achieved by managing the factors affecting deliveries in urban areas. Traffic congestion and time windows of deliveries are the most critical factors in solving distribution planning problems and executing deliveries in an urban environment. Traffic congestion affects the feasibility of delivery schedules and should be taken into account during the initial scheduling, as well as during the execution of deliveries. Time windows should be ensured during the initial scheduling of deliveries, but any rescheduling should guarantee that this restriction is not violated. Contemporary software technology can assist the scheduling and execution of freight distribution in cities. Logistics companies could exploit technologies, such as Cloud Computing (CC) and the Internet of Vehicles (IoV) for optimizing the efficiency of their deliveries. Real-time data of traffic flow and speed of vehicles, collected from sensors, can improve the accuracy of deliveries and increase customer satisfaction. Alongside, the significant volume of data can be stored, processed and utilized, through CC. This technology can quickly provide information and take real-time control over critical processes, to ensure efficiency. The scope of this paper is to describe the architecture of a cloud-based transportation system. The system integrates routing and traffic forecasting algorithms with CC and IoV technologies. The functionality of the system includes the initial, static scheduling of deliveries and the routing of the vehicles. It takes into account the time-windows of the customers and the feasibility of the schedules based on traffic congestion forecasts. Besides, the system collects real-time data of the current situation of the trucks and the real conditions of the traffic in the streets of the city, in order to reschedule the deliveries, if it detects an expected violation of the time windows.

Keywords

Cloud Computing, Internet of Vehicles, Urban Freight Transportation, Vehicle Routing and Scheduling, Dynamic Routing

1. Introduction

Vehicle Routing Problem has been intensively studied from researchers due to the connection with real-life problems, faced by logistics and distribution companies. VRP states that geographically scattered customers around a central depot have to be delivered from vehicles with a specific capacity which should not be violated, while each customer is visited once, by only one vehicle. Some common VRP variants are, time windows (VRPTW), within which the predefined demand must be delivered, as well as the different types of vehicles (VRP with Heterogeneous Fleet – VRPHF), which are characterized by different capacities and costs (Gayalis, Konstantakopoulos, & Tatsiopoulos, 2019). As the number of variants increases, respectively does complexity and running time for optimally solving VRP. New technologies, however, can improve both running time of algorithms, as well as the reliability and on-time deliveries which is significant for logistics companies.

Independently of the company's size, routing and scheduling software which consider multiple VRP variants can be beneficial for companies, both in case of customer satisfaction and of cost savings. While the system is fed with data related to road conditions, traffic congestion and vehicle speed can improve the scheduling of deliveries. Technologies such as the Internet of Vehicles (IoV) can enhance such a system, by gathering data. The development of algorithms which can analyze and process massive amount of data, provide accurate estimation of travel times between two points, and therefore contribute to the initial routing and scheduling. On the other hand, real-time data provide better fleet management and rescheduling of deliveries. The proposed system is delivered through cloud computing services, exploiting the above technologies, offering lower operating costs, efficient processes and flexible resources. In the next sections of this paper, the contribution of CC and IoV in routing and scheduling software is presented in Section. 2. Section 3 introduces the system's architecture and its main functionality. In Section 4 the characteristics of the system are connected with technical solutions, and finally, in section 5 the results of the paper and the further research are discussed.

2. Literature Review

The use of Big Data, Internet of Things (IoT) and Artificial Intelligence (AI), as well as connections between smart machines, are key components of Industry 4.0 (Y. Lu, 2017). According to Tjahjono et al. (Tjahjono, Esplugues, Ares, & Pelaez, 2017), transport logistics will be most affected within supply chain procedures, by the introduction of Industry 4.0, offering both opportunities and threats. More specifically, IoV is an application of IoT which can contribute to distribution of goods. IoV is an open access and dynamic mobile communication system which collects, processes and analyses data, from connected vehicles (N. Lu, Cheng, & Zhang, 2014). By connected vehicles, we refer to the connectivity of vehicles with their internal and external surrounding environment. Vehicle to vehicle (V2V), vehicle to sensor on board (V2S), vehicle to road infrastructure (V2R) and vehicle to internet (V2I) are the main interactions, generating huge amount and different type of data, known as Big Data (Xu et al., 2018). Big Data calls for scalable storage index and a distributed approach to retrieve required results near real-time (Ji, Li, Qiu, Awada, & Li, 2012). According to Nahri et al. (Lbath, Nahri, Boulmakoul, Karim, & Lbath, 2018) exploiting data generated by IoV environment in a centralized manner can have great benefits for traffic control. In this work, we propose the implementation of IoV integrating Big Data analytics.

In the case of distribution and logistics, the IoV technology can significantly contribute both in fleet management and in the scheduling of deliveries and routing of vehicles. V2I connection can provide significant information about traffic conditions, as well as for road accidents. Vehicles can change their route for avoiding such cases and being able to deliver goods to their customers, on time. A smart routing and scheduling system cannot be used and fully exploited without the use of real-time data. Onboard sensors, respectively with V2I, provide real-time data, concerning temperatures, tire pressure, speed, malfunctions and lots of other critical measures. Speed is a parameter which can affect logistics operations, as the average speed is involved and considered for calculating travel time between delivery points, leading to the initial routing of vehicles and scheduling of deliveries. In order, such an amount of data, to be useful for companies, must be analyzed and processed through the appropriate system.

A needful way for software development companies, to provide software, is through cloud computing due to the opportunities it offers. The general idea is that cloud computing (CC), consists of both the data center, which includes the hardware and the software systems and the provided services (Armbrust et al., 2010). A routing and scheduling system offered through cloud computing can significantly benefit the final user, in case of cost, performance, productivity, and accessibility (Marston, Li, Bandyopadhyay, Zhang, & Ghalsasi, 2014). Firstly, no need for buying hardware and software exists, while the cost depends on usage (pay-as-you-go manner). Simultaneously, the provider

is responsible for system upgrades, exclusively in the data center without affecting the operations of the final user. Finally, the end user needs only a browser and an internet connection in order to access and use such an application. By combining all the above technologies, both software development companies and end users can be benefited. The users of the system, which in our case are logistics and distribution companies, can improve their operations and achieve efficient decision making and management, while software providers offer competitive products, which are accessible to more companies of different size and different needs. Finally, in order to understand the contribution of each technology in the transportation system, as well as the advantages of using it, the architecture is analysed and explained in the following sections of the paper.

3. Smart Transportation System's Architecture

The architectural design of the smart transportation system for efficient vehicle routing and scheduling in urban areas is based on the system's concept proposed by Gayialis et al. (Gayialis, Konstantakopoulos, Papadopoulos, Kechagias, & Ponis, 2018). This system will operate in a cloud environment incorporating operational research algorithms and current technological trends for its implementation. The design of the system's architecture and its development are the primary purposes of an ongoing research project. The system includes the main components presented in Figure 1. It is a Decision Support System (DSS) for vehicle routing and scheduling in urban areas, operating in the cloud and exploiting the advantages of cloud computing. The users of the system are logistics companies or other companies offering deliveries of goods in cities. The main modules of the Cloud DSS are the following:

- 1) The **Deliveries Scheduling** module which is responsible for the allocation of customer orders to companies resources (vehicles and depots) in order to serve all customers within their delivery time windows. The calculation of delivery schedules is based on genetic algorithms and time-oriented nearest neighbor algorithms.
- 2) The **Vehicle Routing (Static)** module creates the routes of the vehicles based on the initial schedules with the use of additional improvement algorithms. Time windows are restrictions that should not be violated and scheduling should be made together with the routing of the trucks. That is why this module is always working in parallel with the Delivery Scheduling module, and they act as one in order to calculate the static routes. Static routing uses geographical data like maps and network of streets from third party data providers. Traffic prediction data are also an input to Vehicle Routing (Static) module in order to check the feasibility of the routes in real-life circumstances concerning the time-windows of the deliveries.
- 3) The **Traffic Data Prediction** is responsible for the estimation of the traffic and its output is used by the Vehicle Routing (Static) module as described above. In order to calculate the estimation of the traffic of the specific days on which the routes are planned, traffic forecasting algorithms are used. The necessary data to predict traffic are retrieved by third-party data providers, such as mapping companies, GIS software providers or public organizations.
- 4) The **Vehicle Routing (Dynamic)** module creates new routes and reschedules the deliveries every time a problem or a required transformation of the schedule is reported by the user of the system (company). Besides, the system checks the feasibility of the routes and possible violations of the time windows dynamically, according to the situation of the truck and the traffic jam. In order to achieve this it uses as input big data processing results created by the next module of the system.
- 5) The **Big Data Processing** module is an important component for the dynamic routing functionality of the system. It integrates IoV technology and real-time traffic data information, in order to estimate the possible violation of the time window restrictions due to the traffic jam, unexpected incidents to streets or problematic operation of the trucks. It collects data for the position and the condition of the vehicle using appropriate sensors, GPS devices or mobile phones and tablets. It also collects real-time traffic data in conjunction with the vehicles' data in order to have an accurate estimation of the arrival of the vehicles to the company's customer and to detect inconsistencies of schedules.
- 6) The **Monitoring** module is the part of the system that offers visualization of the routes produced by the Vehicle Routing modules (both static and dynamic). Through this module, routes are sent either to vehicle devices (mobile phones or tablets) through telecommunication networks or to company's information systems for further analysis and communications with the drivers of the trucks. This module can also integrate routes with the dynamic condition of the vehicle using big data processing outputs.

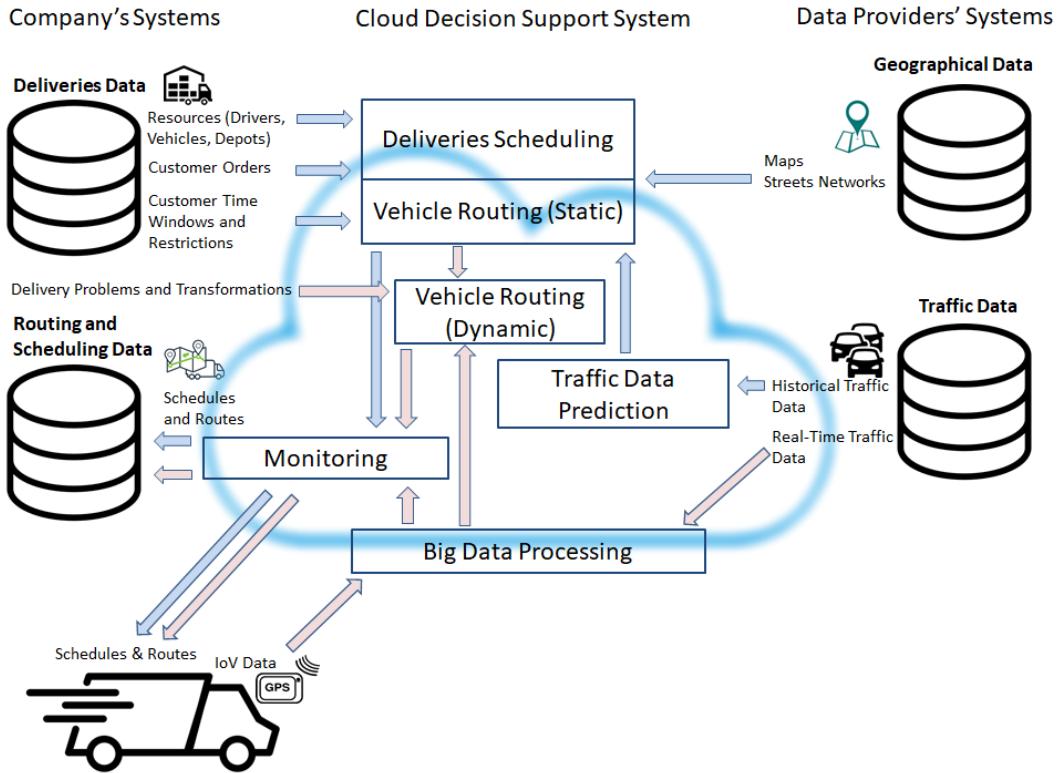


Figure 1: Smart Transportation System's Architecture

Figure 1 depicts the Cloud System and its modules described above (main-central part of the architectural scheme), as well as the interfaces with the systems of its users (left part), as well as third-party systems (right part). The arrows depict the data flow acting as an input in the system or as an output of it, plus the data flow between the modules. Blue arrows refer to the first level of routing and scheduling (static), while the red arrows characterize the data flow for the second level, that is the dynamic routing and rerouting of the trucks.

For every part of the system's architecture, various technologies have been explored and several of them have already been selected and are going to be implemented for the development of the cloud system. These technologies are described in the next section of the paper.

4. Technologies for System Development

The cloud decision support system is the core element of the proposed system's architecture. It will be implemented in a state-of-the-art cloud technology offered by the big providers of cloud computing (like Microsoft, Oracle or Amazon) and it will be using the approach of Infrastructure-as-a-Service or the approach of Platform-as-a-Service, depending on the final selection of the cloud computing technology. The applications (modules) of the transportation system will be developed over these platforms and infrastructures and will be offered to end users as Software-as-a-Service. Zhang et al. in their paper "Cloud computing: state-of-the-art and research challenges" (Zhang, Cheng, & Boutaba, 2010) describe the aforementioned architectural layers of cloud computing comprehensively. This cloud computing system can easily host and deliver services over the Internet, but it needs reliable and easily applied interfaces with user's systems and third-party data providers' systems to achieve this. The most challenging interfaces are the ones with the companies' systems in order to send and receive the data presented in the left part of Figure 1. Input data to the cloud system will be transferred through Application Programming Interface (API) services, and the communication of the APIs will be made through the Representational State Transfer (REST) protocol or Simple Object Access (SOAP) protocol. This approach needs the user company to extend its systems and prepare an infrastructure to communicate with the transportation system's APIs. Alternatively, it could be developed a web interface in ASP.net.2 technology for no IT expert companies in order to upload data files of their deliveries, vehicles, depots and so on. In this case, Angular platform will be used for dynamic HTML pages to build mobile and desktop

web applications for data input. Output data from the cloud system can be sent through APIs and REST or SOAP protocols, using the same or different ID API number with the input data.

Cartographical data from geographical systems will be retrieved using APIs created by their providers. The geocoding of the end point of delivery will be succeeded through REST protocol and through JavaScript Library which has many capabilities of interaction on the maps.

Vehicle routing and scheduling algorithms, as well as the traffic forecasting algorithms, will be developed in python or .net programming languages, but C++ is still an option, due to its extended available numerical libraries.

The big data processing technology integrates IoV data from vehicles devices and online traffic data from data providers. This technology will use various techniques and processing methods like NoSQL databases for unstructured data, knowledge discovery tools, data virtualization, data integration, stream processing, parallel processing. Yue and Jiang (Yue & Jiang, n.d.) present an overview of the recent methods in supporting big data management and analysis for the geospatial and mapping domain. The objective of big data management needs virtualization into cloud architectures using the cloud management platforms for Infrastructure-as-a-Service, exploiting the cloud architecture in which the transportation system will be built. The development of the cloud computing infrastructure is the next phase of the research project while the final selection of the technologies is going to materialize soon.

5. Conclusions and Further Research

The proposed architecture of the transportation system incorporates the current trends in the application of industry 4 in supply chain and logistics. It integrates static data for vehicle routing and scheduling and real-time data for monitoring and rescheduling of routes, avoiding inconsistencies in the schedules. It is a decision support system that can offer efficiency in the delivery of goods and keep in a high level the customer satisfaction of its users. Cloud computing is used in order to build and provide the system for decision making in routing and scheduling operations of logistics companies or generally of companies that need to prepare their distribution plans in urban areas. The development of the designed system is part of an ongoing research project carried out by the Industrial Engineering Laboratory of the National Technical University of Athens in partnership with a software company.

Acknowledgment

The present work is co-funded by the European Union and Greek national funds through the Operational Program "Competitiveness, Entrepreneurship and Innovation" (EPAnEK), under the call "RESEARCH-CREATE-INNOVATE" (project code: T1EDK-00527 and Acronym: SMARTRANS).

References

- Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., ... Stoica, I. (2010). A View of Cloud Computing. *Communications of the ACM*, 53(4), 50–58. <https://doi.org/10.1145/1721654.1721672>
- Gayialis, S. P., Konstantakopoulos, G. D., Papadopoulos, G. A., Kechagias, E., & Ponis, S. T. (2018). Developing an Advanced Cloud-Based Vehicle Routing and Scheduling System for Urban Freight Transportation. In I. Moon, G. M. Lee, J. Park, D. Kiritsis, & G. von Cieminski (Eds.), *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0* (pp. 190–197). Cham: Springer International Publishing.
- Gayialis, S. P., Konstantakopoulos, G. D., & Tatsiopoulos, I. P. (2019). Vehicle Routing Problem for Urban Freight Transportation: A Review of the Recent Literature. In A. Sifaleras & K. Petridis (Eds.), *Operational Research in the Digital Era -- ICT Challenges* (pp. 89–104). Cham: Springer International Publishing.
- Ji, C., Li, Y., Qiu, W., Awada, U., & Li, K. (2012). Big Data Processing in Cloud Computing Environments. In *2012 International Symposium on Pervasive Systems, Algorithms and Networks* (pp. 17–23). <https://doi.org/10.1109/I-SPAN.2012.9>
- Lbath, A., Nahri, M., Boulmakoul, A., Karim, L., & Lbath, A. (2018). ScienceDirect ScienceDirect ScienceDirect IoV distributed architecture for real-time traffic data analytics IoV distributed architecture for real-time traffic data analytics. *Procedia Computer Science*, 130, 480–487. <https://doi.org/10.1016/j.procs.2018.04.055>
- Lu, N., Cheng, N., & Zhang, N. (2014). Connected Vehicles : Solutions and Challenges. *IEEE Internet of Things Journal*, 1(4), 289–299. <https://doi.org/10.1109/JIOT.2014.2327587>
- Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, 6, 1–10. <https://doi.org/10.1016/j.jii.2017.04.005>
- Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2014). Cloud computing — The business perspective ☆. *Decision Support Systems*, 51(1), 176–189. <https://doi.org/10.1016/j.dss.2010.12.006>
- Tjahjono, B., Esplugues, C., Ares, E., & Pelaez, G. (2017). What does Industry 4.0 mean to Supply Chain? *Procedia Manufacturing*, 13, 1175–1182. <https://doi.org/https://doi.org/10.1016/j.promfg.2017.09.191>

- Xu, W., Zhou, H., Cheng, N., Lyu, F., Shi, W., Chen, J., & Shen, X. S. (2018). Internet of Vehicles in Big Data Era. *JOURNAL OF AUTOMATICA SINICA*, 5(1), 19–35. <https://doi.org/10.1109/JAS.2017.7510736>
- Yue, P., & Jiang, L. (n.d.). BigGIS : How Big Data Can Shape. *2014 The Third International Conference on Agro-Geoinformatics*, 1–6. <https://doi.org/10.1109/Agro-Geoinformatics.2014.6910649>
- Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing : state-of-the-art and research challenges. *Journal of Internet Services and Applications*, 7–18. <https://doi.org/10.1007/s13174-010-0007-6>

Biography / Biographies

Sotiris P. Gayialis has a Diploma in Mechanical Engineering (1997) and a Ph.D. (2008) in Business Process Management and Supply Chain Management from the National Technical University of Athens (NTUA), Greece. He is currently a Teaching and Research Associate of Supply Chain Management Processes in the Sector of Industrial Management & Operations Research at NTUA. He is also an adjunct faculty member of Hellenic Open University. His academic interests are Logistics and Supply Chain Management, Business Process Management, Business Process Improvement, Operations Management and Management Information Systems. He has a twenty year experience in research projects and management consulting. He has participated in a large number of business process improvement and reengineering projects, enabled by IT technology. He has published more than seventy papers in journals, chapters for books and international conferences.

Grigorios D. Konstantakopoulos is currently a PhD student at the National Technical University of Athens (NTUA), in School of Mechanical Engineering. He has studied Mechanical Engineering at NTUA (2017), with specialization in Industrial Management and Operational Research, and presented a diploma thesis entitled “Vehicle Routing Systems for Urban Freight Transportation: Field Review and Specifications”. His academic interests revolve around the areas of Vehicle Routing Problem, Operational Research, Business Process Management, Logistics and Supply Chain Management. He has published academic and conference papers on these areas.

Evripidis P. Kechagias is currently a PhD student at the National Technical University of Athens, School of Mechanical Engineering, Sector of Industrial Management and Operational Research. He has studied Mechanical and Industrial Engineering at National Technical University of Athens (2017) and presented a diploma thesis entitled “Business process management integrated with risk management in the construction industry” that was awarded the honors degree. He is also a MSc (Master of Science) student in the field of Technoeconomic studies. His academic interests revolve around the areas of Information Technologies, Business Process Modeling, Analysis and Management, Operational Research, Information System Management, Knowledge Management, Project Management, Industrial Management, Enterprise Resource Planning Systems, Logistics and Supply Chain Management, Production Decisions and Planning. He has published academic and conference papers on these areas.

Georgios A. Papadopoulos is a teaching Staff at the School of Mechanical Engineering NTUA Sector of Industrial Management & Operations Research and deals with educational, research and administrative tasks. He has studied Mechanical and Industrial Engineering at NTUA (1994) and followed post-graduate studies at the university of wales, Cardiff business school, UK, obtaining a Master of Business Administration (MBA) (1996). He also obtained a PhD at the National Technical University of Athens, School of Mechanical Engineering, Sector of Industrial Management and Operational Research and his thesis was entitled: "Support of Production Planning Decisions in Co-operation with Integrated Enterprise Resource Planning System (ERP)" (2009). He has participated in many projects and publications around the areas of Logistics, Production Decisions, Production Planning and Control Systems, Information Systems, Web Design and Development, Application Development.