

Green Transportation and the Role of Operation Research

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Abstract. Transportation industry, as the carrier of goods and passengers, is undeniably one of the fundamental infrastructures, necessary for economic and industrial growth and development. Road transportation, in this amidst, has still kept its popularity, and in spite of air, sea and rail transportation developments, companies rely greatly on road transportation as the most dependable choice yet. At the same time it is one of the hugest consumers of petroleum products, and thus a big contributor to greenhouse gases and CO₂ emissions in the air. Being a threatening issue, environmental impacts of different industries as a whole, and transportation pollution as specific, ought not to be neglected anymore and immediate and proper studies as well as actions need to be thought of in dealing with this predicament.

“Green Transportation” is a highly interdisciplinary area and researchers and scholars of different realms of knowledge, including automotive engineers, policy makers, management intellectuals, urban planners, chemical engineers, and others, are trying to reduce CO₂ emissions from the sector. Them amongst the lagging behind, but pivotal and accommodating role of operation research (OR), with its becoming tool of optimization, has not been fully regarded and needs to be more deeply reviewed. This paper tries to bridge this gap by providing an insight into what OR may contribute to the problem, by reviewing how it has already done it and how it is going to.

Keywords: Green Transportation, Operation Research (OR), Vehicle routing problem (VRP), Supply chain reengineering, Intelligent Transportation Systems (ITS)

1. Introduction

Transportation sector, as the everyday carrier of millions of tons of freight and numbers of passengers, is the irreplaceable and undeniable foundation of economic and industrial development. Even the advancements in building a virtual world, which hoped to cut down on physical transportation by virtual transference, not only could not decline the worldwide dependency on the sector, but also a rapid growth is being witnessed. Nonetheless, at the same time of its importance to the world life, it is a danger to the world life, since it is one of the hugest consumers of petroleum products and hence a great contributor to existing pollutant particles in the air. The hazardous and fatal emissions from transportation sector could seriously damage global health. The sector accounts for approximately 15% of overall greenhouse gas (GHG) emissions and 23% of overall CO₂ emissions, which is the most prevalent of all GHGs [1]. These global CO₂ emissions from transportation sector have grown by 45% from 1990 to 2007, and are expected to continue to grow by approximately 40% from 2007 to 2030 [1].

Among all the modes of transportation then, despite all developments in air, sea and rail transportation, companies continue to rely greatly on road transportation, due to its low cost, high flexibility, and faster response time [2]; and this leads to the domination of road sector CO₂ emissions, where road freight alone accounts for 30% to 40% of total CO₂ emissions of the sector [1]. So, it is normal that “Greening” road transportation becomes a top-ranking obligatory task.

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Bjorklund [3] defines “Green Transportation” as: “Transportation service that has a lesser or reduced negative impact on human health and the natural environment when compared with competing transportation services that serve the same purpose”.

One realm of knowledge which could deliver considerable contributions to this agenda is operation research (OR). However, its potentialities are not well exposed yet and OR advocates have not attended the issue as it deserves. They have a prime toolbox of optimization ready to correct any “incorrect utilization trend”. This paper is going to act as a stimulator to motivate forthcoming OR studies be in this field. This short communication is going to elaborate on how OR has already been helpful and how it is going to continue to be helpful.

2. The Role of Operation Research

Originated in the efforts of military planners during World War II, once “Operation Research” assisted war makers in devastating the planet earth and its creatures, and today it is ready to deliver its contributions to its fullest potentials in order to expiate its guilt by saving the planet and its dwellers this time.

The first systematic use of operation research (OR) was during World War II, in 1941 in England, where British army was not completely familiar with the optimized utilization of the newly invention of radar by its scientists. Thus they gathered a group of researchers from different disciplines to employ effective mathematical techniques and analyze operational data, which led to the articulation of some suggestions that could increase defending capability of England to approximately 10 times more than what it used to be. This and many other similar accomplishments by OR groups in military contexts, soon broadcasted its popularity worldwide, and by the 1950s it had already been adopted by industries [4].

OR (also referred to as management science or decision science), is a systematic approach toward modelling complex real world managerial problems. Employing techniques from other mathematical sciences, such as mathematical modelling, statistical analysis, and mathematical optimization, it arrives at optimal or near-optimal solutions to complex decision-making problems [5]. Its tools and procedures can address a variety of problems including critical path analysis or project planning, network optimization, facility location, optimal search, routing, supply chain management, transportation, and so on.

In spite of the fact that its role in serving green transportation agenda is relatively overlooked and neglected and it has lagged behind compared to other disciplines of science in this realm, OR is able to play such accommodating role and contribute to reduction of CO₂ emissions from road transportation by its optimization tools. Here we try to show how OR have so far (more implicitly) served green transportation paradigm, and how it is going to do so. This is very important to encourage OR academia to join the issue, since they can bring about notable improvements in the field.

2.1. Utilization trends modification

Policy makers have developed public transportation, bicycle and pedestrian facilities to their fullest capacity. Cultural actions have been done efficiently and people are now motivated to use more active and environmental-friendly transportation modes. Regulations toward limiting automobile use have been optimally deployed. Alternative cleaner burning fuels have been introduced and vehicle manufacturers have employed top-notch technologies to produce first-class vehicles congruent with the greatest world standard emission protocols. Information technology has well-progressed and the ease of online shopping has cut physical transportation activities. But is this the end of the road? Aren't there any other measures to yet reduce CO₂ emissions from the remaining transportation activities?

Indeed, even in the foregoing utopia, there are sure some more problems. Economic sector can never act independently from transportation sector, especially road transportation, and firms continue to ship their freight to and from their plants by road transportation fleet. Even if they renew their fleet of vehicles to the greenest available ones, they are still using them and they are using them in unfitting, improper, and non-scientific manners. They do not consider and study their inappropriate utilization trends, which impose unwanted additional emissions on the environment.

This is where OR enters and delivers its contribution. OR with its toolbox of optimization is the best alternative to correct and modify road transportation wrong utilization trends by freight carriers. This role is especially highlighted when it is known that inevitable road freight, stands as the greatest cause of CO₂ emissions of the sector; 30% to 40% of total CO₂ emissions of the sector come from freight transportation [1]. Since, road freight could not be eliminated or restricted, at least it has to be corrected.

To the best of our knowledge, OR as it is at the beginning of its way to green transportation and yet has a long way to go, has so far contributed to green transportation paradigm through the study of two of its well-known affairs; i.e. vehicle routing, and supply chain reengineering. The sub sections of this section discuss these two approaches of OR toward green transportation.

2.1.1. Vehicle routing problem with green transportation considerations

Vehicle routing and scheduling problem (VRSP) is a well-known conventional OR problem. Since the introduction of its prevalent variant, i.e. capacitated vehicle routing problem (CVRP) by Dantzig and Ramser [6], it has been well studied and many different solution algorithms including exact, heuristic and meta-heuristic approaches have been developed.

The basic CVRP can be described as follows: a set of homogeneous vehicles each of capacity Q , located at a central depot and a set of customers with known locations and demands are given. The customers' demands are to be satisfied by deliveries from the central depot. Each vehicle route must start and end at the central depot and the total customer demand satisfied by deliveries on each route must not exceed the vehicle capacity, Q . The objective is to determine a set of routes for the vehicles that will minimize the total cost. The total cost is usually proportional to the total distance travelled and may also include an additional term proportional to the number of vehicles used if the number of routes may vary [7].

Indeed, CVRP studies have been serving green transportation paradigm long before its birth; in fact as early as their introduction by Dantzig and Ramser in 1959. Nonetheless, this contribution has always been completely implicit and unconscious, and researchers have often been totally unaware of the beneficial connotations of their works on the environment.

All the while that CVRP aims at minimizing total travelling kilometres, and total assigned vehicles, it is satisfying green transportation requirements by reducing consumption level and consequently reducing the CO₂ emissions from road transportation. Thus, all the great and huge body of the literature on vehicle routing deserves to be acclaimed and admired here on behalf of green transportation for their long contribution. For a review on the recent and state-of-the-art coverage on models and solution algorithms to vehicle routing problem and its different variants, the reader may be encouraged to refer to the study of Cordeau et al. [8] and the book of Golden et al. [9].

The contribution of vehicle routing surveys is not limited to this implicit and unconscious contribution by minimizing travel distance and vehicle numbers, though, and many more explicit factors related to green transportation issues could be considered in a CVRP model. Fortunately, the academia has relatively activated on this area during the past few years and especially in the being year (2011) a few studies with more explicit contributions have been published in peer-reviewed journals.

Seemingly, the awareness with the contribution of CVRP to green transportation was initiated with the studies of Sbihi and Eglese [7] and the PhD dissertation of Palmer [10]. In a working paper for Lancaster University Management School [7] Sbihi and Eglese review the literature related to vehicle routing in order to find the relationship between vehicle routing and scheduling and green logistics. Providing an introduction to green logistics issues that are relevant to vehicle routing and scheduling including discussion of the environmental objectives that should be considered, they cannot find much literature that links VRSP models with the Green Logistics issues. However, regarding the existing literature they argue that reduction in total distance will in itself provide environmental benefits due to the reduction in fuel consumed and the consequent pollutants. Palmer [10], on the other hand, suggests an integration of logistical and environmental aspects into one freight demand model with the aim of enhancing policy analysis.

Following the aforementioned rise in the area, a number of worthwhile studies with direct environmental considerations in their objective functions were launched. Citing the most relevant and explicit ones to the

considerations of green transportation we may start by mentioning the introduction of the “Pollution Routing Problem (PRP)” by Bektas and Laporte [11]. They develop PRP as an extension of the classical VRP with a broader and more comprehensive objective function that accounts not only the travel distance, but also the amount of green-house emissions, fuel, travel times and their costs. They shed light on the tradeoffs between various parameters such as vehicle load, speed and total cost, and offer insights on economies of environmental-friendly vehicle routing. Xiao et al. [12] regard Fuel Consumption Rate (FCR) as a load dependant function, and add it to the classical CVRP to extend traditional studies on CVRP with the objective of minimizing fuel consumption. They call their modelling approach FCVRP and develop a simulated annealing algorithm with a hybrid exchange rule to solve it. Their results show FCVRP model can reduce fuel consumption by 5% on average compared to the CVRP model. Erdogan and Miller-Hooks [13] introduce Green Vehicle Routing Problem (G-VRP). Their proposal particularly aims at aiding organizations with alternative fuel-powered vehicle fleets in overcoming difficulties that exist as a result of limited vehicle driving range in conjunction with limited refuelling infrastructure. Other studies include [14; 15; 16; 17].

The above-discussed studies were all the studies that we could find in the most online peer-reviewed journals. Apparently, all these studies have been published in 2011(except one of them, which is published in 2010). This shows that the topic is at its very beginning and is still too attractive and demanding.

2.1.2. Supply chain reengineering with green transportation considerations

Another area of OR activities which can have lofty contributions to green transportation agenda, is supply chain reengineering with green transportation consideration. Many transportation activities in supply chain affairs are additional due to unnecessary dispersal of activities and processes which could be centralized in a single plant.

In fact it is one step further to CVRP, where we minimize required alternative routes to perform supply chain activities, and then in the final determined routes yet we try to choose the best through a CVRP with green transportation considerations.

Unfortunately, in spite of its great capabilities in this area, this is where OR has been inactive so far and is lagging behind. Although, different previous attempts in reengineering supply chains, may have implicitly reduced environmental impacts related to transportation activities, these contributions remain unknown to us, just same as that they are unknown to the unaware authors of those works. Hence, we could not cite any particular study in this regard except the study of Yazan et al. [18]. They examine the impact of process disaggregation and specialization on the environmental performance of the supply chain of a leather upholstery company, by developing an enterprise input–output model that relates geographical information with production processes and transportation routes. However, their reengineering outcomes seem to have unsuccessful connotations with regard to CO₂ emissions; their results show that the annual CO₂ caused by the local transportation on each route in the current supply chain, which is approximated to be 756.7 tons, is increased to 1388.7 tons in the reengineered supply chain and this shows reengineering failure in environmental sense, although they achieve economic gains from reengineering the system, and at least define a trade-off between the economic gains from reengineering the system and environmental performance of the chain.

As we mentioned this study is the only specialized study we could cite in the proposed domain, i.e. supply chain reengineering with green transportation consideration. However, at this point we ought to acknowledge that very often researches related to the “Green Supply Chain” paradigm (or Green Logistic in a narrower and more related manner) consider transportation issues in the context of their inclusive practices to reduce general environmental impacts of supply chain activities; but our purpose regarding supply chain reengineering with green transportation consideration, calls for attempts which are exclusively directed toward transportation activities of the chain rather than other production and procurement activities. Hence this area demands more attention by OR scholars and profound works could be initiated by integrating vehicle routing, supply chain activities, and environmental factors.

2.2. OR and the Development of ITSs

The major contribution that OR toolbox, with its primary tool of optimization delivers to green transportation agenda, is through the modification of utilization trends discussed in the previous sub-section. However, OR has also largely contributed to the development of Intelligent Transport Systems (ITSs). ITSs refer to the integration of information and communication technologies with transport infrastructure to improve economic performance, safety, mobility and environmental sustainability of transportation activities [19]. These systems apply advanced technologies of electronics, communications, computers, control and sensing and detecting in all kinds of transportation system in order to improve safety, efficiency and service, and traffic situation through transmitting real-time information. This collection of technologies, systems, and transportation management concepts aims at making surface transportation more efficient and safer [20].

Operations research methodologies in real-time decision-making can provide ITSs with qualified supporting software. This role has been variously examined, and on top of the related research is the study of Crainic et al. [21] who assess the contribution of OR in the development of ITSs. They discuss how the introduction of better decision-support software based on OR models and methods, could very significantly improve the ultimate performance of ITSs. They believe deployment of OR tools opens up the possibility of enhanced customer service and increased productivity by re-routing vehicles in real-time to serve new requests. More researches make use of OR toolbox to support the performance of ITSs including [22; 23; 24].

Therefore, the development of ITSs could be a nice challenging touchstone for OR methodologies, and OR scholars are required to collaborate with IT engineers in order to progress these technologies. There are still many other factors, including environmental ones, which could be considered in the development of ITSs and this ground is full of attractions and potentialities for OR advocates. A significant line of research is to address the issues of real-time dispatching, routing, and re-routing of vehicles in response to changes in demand, travel time or other conditions of travel [21].

3. Discussion and Conclusion

Transportation sector is the irreplaceable infrastructure upon which economic and social development is possible. Million tons of freight and numbers of passengers are carried by the sector each day. People go to their work places, cargoes are shipped to and from plants, students are given ride to their schools, families go shopping for their groceries and many more activities are dependent on the sector. However, at the same time of its importance to the global life it is a danger to it, since it is one of the hugest consumers of petroleum products and hence a prime creator of the existing harmful particles including greenhouse gases and CO₂ as the most prevalent of them, in the air.

It is a while that an urgency to reduce these emissions has been realized and global communities have been activated under the umbrella of the “Green Transportation” paradigm. This is the best house to gather all attempts toward securing the planet and its living creatures. Mechanical engineers, policy makers, urban planners, environmental engineers, management scholars, industrial engineers, social and behavioural advocates, chemical engineers, business administrators, transportation researchers, automotive engineers and others in many more fields of knowledge, are now working together for greening the transportation sector. Operation research, being one of them, seems to have been lagged behind. We put particular emphasis on the role of operation research in this paper and referred to its already initiated contribution, and called for more activities in this regard. With its optimization tools, it contributes to green transportation agenda through two of its well-known studied problems; i.e. vehicle routing and supply chain reengineering. Moreover, OR is a decision support to ITSs and this way helps accomplishing green transportation requirements.

4. References

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