

# Scheduling and pricing of services to minimise CO<sub>2</sub> emissions of delivery vehicles

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## Summary Abstract

Previous research found that minimising emissions often conflicts with maximising profit in service delivery. In this study, we consider a service scheduling problem and propose a new approach to the problem which applies low-emission vehicle scheduling techniques with dynamic pricing to reduce CO<sub>2</sub> emissions and maximise profit. Incentives are included in the service prices to influence the customer's choice in order to reduce CO<sub>2</sub> emissions. To help the company determining the incentives, our approach solves the problem in two phases. The first phase solves vehicle scheduling models with the objective of minimising CO<sub>2</sub> emissions and the second phase solves a dynamic pricing model to maximise profit. This approach is tested through numerical experiments.

**Keywords:** Service delivery, Vehicle scheduling, Minimising CO<sub>2</sub> emission, Dynamic pricing, Mathematical programming

## Purpose

Since the introduction of legislation and policies such as the Kyoto Protocol in 1998, companies are under increasing pressure to reduce the levels of carbon dioxide (CO<sub>2</sub>) and other greenhouse gas emissions associated with their operations. The main contributor to increased carbon dioxide level in the atmosphere is the burning of fossil fuels, and transportation is a major contributor of emissions (Ohnishi, 2008). There has been extensive research (e.g., Apaydin and Gonullu, 2008; Ubeda et al., 2011; Li et al., 2013; Ubeda et al., 2014) on vehicle routing problems by both practitioners and academics, but the focus is

mainly on minimising the total travel distance or time. More recent research has been driven by green vehicle routing or scheduling problems where the objective is to minimise CO2 emissions (e.g., Figliozzi, 2010; Jabali et al., 2012). The minimisation of the total distance travelled is not always the same as minimising the total CO2 emissions. Although the two are related, the relationship is not a proportional one.

In this study we consider a problem of scheduling services at customer sites by allocating them to engineers each with a vehicle. The customer sites considered are all in a confined geographical area, therefore the problem can be considered as a vehicle scheduling problem (VSP) rather than vehicle routing one. The VSP is to allocate the service tasks to the schedules of a fleet of vehicles initially located at a depot. Since traffic conditions have a significant influence on CO2 emissions, the cost of emissions is modelled as being time-dependent to capture congestion patterns. Customer orders arrive dynamically and each customer order comes with a preferred time window. We aim to schedule the service tasks and the vehicle traveling to reduce CO2 emissions whilst maximising profits by influencing customers' choice of time windows through pricing incentives. To the best of our knowledge there is no previous research that proposes to reduce CO2 emissions through vehicle scheduling using a dynamic pricing model. In this study, we develop a new time-dependent CO2 emissions minimisation scheduling model and an improved incentive dynamic pricing model, and use computational studies to simulate the situation of a service delivery company to test the proposed approach. The results show that these models help reduce the total amount of CO2 emissions and increase profitability.

## **Methodology**

We propose a new approach to this problem which applies both low-emission vehicle scheduling techniques and dynamic pricing. The approach is shown in Figure 1. An initial schedule of the vehicles is constructed based on information of the initial set of tasks. Whenever a new customer order arrives with an original time-window preference, prices for the task to be performed in different time windows are determined and presented to the customer; the new task will be scheduled to start in the time window that the customer selects based on the price information. The actual start times and the vehicles for the unserved existing tasks may be changed in the schedule in order to minimize the emission cost. However, their agreed time windows will remain satisfied in the updated schedule. Therefore, we need to make both pricing and scheduling decisions each time a new customer order arrives. These two decisions are interrelated and so an integrated model would be difficult to formulate and solve. We propose to make these two decisions in two phases as outlined below.

The first phase deals with the scheduling decisions. Although the scheduling decision needs the information about the customer selection of time window for the new task which in turn needs the pricing decisions, we know for sure that the new task must be in one of the time windows. Thus, we solve several possible scheduling problems each assuming the new task being allocated to a different time window. The solution of each problem provides a schedule with minimised emission costs with the new task scheduled to start in the corresponding time window.

The second phase makes pricing decisions using the emission costs obtained in the first phase, which extended the work of Campbell and Savelsbergh (2006). Based on the new customer's original preference, the probabilities for the customer to choose each time window are estimated. The way of these probabilities changing with pricing changes is

assumed to be known. The pricing problem in the second phase can then determine the incentives/prices for each time window so that the expected profit is maximised. Once the customer selects a time window based on the pricing results, the corresponding schedule obtained in the first phase can be used.

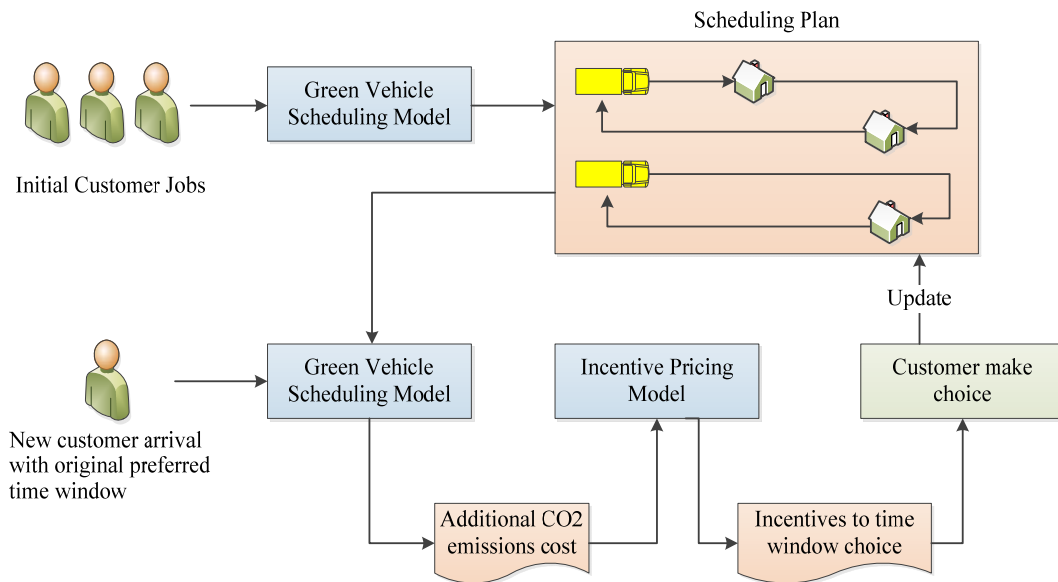


Figure 1- The framework of the solution approach

## Findings

The green scheduling and pricing approach is tested using numerical experiments. In the experiments, the whole planning horizon is set to be one day. The whole period is divided into five equal time windows that customers may choose for their requested service to start. Reflecting the congestion conditions, the profile of emission cost is expressed using ten time slots. We generate an initial set of customers at the beginning of the day and simulate subsequent customer arrivals using Poisson process. For each customer arrival, a preferred time window is randomly generated. The probability for the customer accepting each available time window is calculated using a triangular distribution with the preferred time window as the mode. The green scheduling model is run to obtain the emission cost for the task being performed in each available time window. The pricing model is then run to decide the incentives given for each of these time windows. The customer's final choice of the service time window is randomly generated using the adjusted probability profile. The task is then scheduled in the selected time window, and this customer becomes an existing customer.

We compare our approach with the green scheduling method without incentives. The green scheduling method is implemented using the same simulation framework. Results show that our integrated incentive model reduces the CO<sub>2</sub> emission cost by 14.2458% on average, compared to a green vehicle scheduling method without incentive. Meanwhile the average profit increases by 3.5629%. The average results show that the incentive pricing model can both increase profits and reduce carbon dioxide emissions significantly.

We carried out three sensitivity tests, including the ratio of existing customers, variation of emissions level over congested/non-congested period and patterns of customer arrivals. The results are shown in Table 1, Table 2 and Table 3 correspondingly. The results showed that with less dynamics in the system, i.e., less new coming customers, or lower emission variation, the reduction in CO<sub>2</sub> emissions and profit improvement would be lower. The patterns of customer arrival also affect the results.

*Table 1-Ratio of existing customers*

The ratio of existing customers	Emission cost savings (%)	Improvement in profits (%)
<b>35%</b>	14.2458	3.5629
<b>51%</b>	9.7793	2.1068
<b>67%</b>	9.2096	2.0868

*Table 2- Variation of emission level over congested/non-congested period*

Variation of emissions level	Emission cost savings (%)	Improvement in profits (%)
<b>High</b> (max/min = 5)	14.2458	3.5629
<b>Low</b> (max/min = 2.5)	5.6391	1.0220

*Table 3- Patterns of customer arrivals*

Patterns	Arriving customers during [0,500]	Arriving customers during [500,1000]	Emission cost savings (%)	Improvement in profits (%)
1	10	10	13.2007	3.0009
2	5	15	12.1825	2.8411
3	15	5	13.8967	3.2235

## **Contribution**

In this study, we considered a problem of scheduling engineers with vehicles to provide services. We proposed a new two-phase approach to this problem. The approach was tested through computational experiments. The results showed significant reduction in the amount of CO<sub>2</sub> emissions as well as significant improvement in the total profits. The approach proposed is an attempt in the new direction of research to exploit the combination of Green VRP and Dynamic pricing techniques. We assumed that the level of CO<sub>2</sub> emissions depends only on different time slots of a given day. As time-dependent green vehicle routing problem is a relatively new research field, we have little information of real life CO<sub>2</sub> emissions. As research on calculation of the amount of CO<sub>2</sub> emissions continues to develop, additional factors that influence the amount of CO<sub>2</sub> emissions, such as actual travel time or distance can be considered, which provide future research topics.

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