

LONG-HAUL TRUCK AND DRIVER SCHEDULING PROBLEM WITH TRANSFER OPTIONS: A CASE STUDY IN CEMENT DISTRIBUTION

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ABSTRACT

Purpose: This paper discusses a typical practical problem in cement distribution of a leading cement industry in Indonesia. Currently, majority of cement distribution in Java Island have been dominated by trucks. Due to traffic and congestion, the delivery in some cities are delayed because their trucks have not returned from other delivery completion. The company has initiated several logistics improvements including the use of transfer options to minimize the overall driving time. Based on this strategy, this paper proposes a model of simultaneous vehicle routing and truck driver scheduling problem with transfer options. We also consider the Hours of Service (HOS) regulation in developing the schedule. Some numerical experiments based on real cases will be conducted to verified the developed model.

Design/methodology/approach: This research proposes a mixed integer programming followed by heuristics approach for solving this problem. The model contains 4 constraints which are time setting, time windows, HOS regulation, and transfer constraints. Based on this algorithm we develop a decision support system (DSS) based on visual basic application (VBA) which is easy to modify and user friendly.

Findings: This research will find the feasible routes and schedule for driver that still comply the Indonesian driver and traffic regulation and achieve the objective function.

Practical implications: This research solved a case study with real data from one of leading cement distributor in Indonesia. By the result, we can suggest the best possible routes and schedule for drivers, also the best option for transfer shipment strategy.

Originality/value: This research will solve the simultaneously vehicle routing and truck driver scheduling with transfer options that never been studied before. This study will also take into account single shipment and multiple time windows constraints.

Keywords: Vehicle Routing Problem, Truck Driver Scheduling Problem with Transfer Options, Cement Distribution, Hours of Service Regulation

Introduction

Majority of cement distribution in Java island have been dominated by trucks. The high traffic of the trucks increases traffic jam on the road. This congestion will cause delivery time to be longer and less competitive. For example, Jakarta and Surabaya, which has 734 km distances, normally can be reached within 14 hours. But if there is congestion, especially near the holiday, the travel time will increase up to 18-30 hours. As a result from this long journey, the driver fatigue is often contributing in accidents on the roads.

To reduce the number of accident caused by driver fatigue, government issued some rules regarding traffic and road transport. In this regulation, the truck driver should only be able to drive a maximum of 8 hours, and under certain conditions is allowed up to 12 hours including 1-hour rest period. This regulation will certainly increase the total travel time from trucks.

For the companies, this long delivery time led to a shortage of standby fleets at the depot. The distribution companies that operate delivery across cities in Java island should provide a huge amount of capital to invest in buying more trucks. Companies can also choose the second option, by employing a third-party

logistics, but this also require additional cost. The shortage fleets at the depot can delay the delivery to other destination. This also can lead to uncompetitive market because the amount of their product in some areas are insufficient.

This research is motivated by the problem faced by a leading cement company in Indonesia. They distribute their product from their plant to their distributors that spread in Java. Cement itself has a distinct characteristic that make it hard to combine with distribution of other products, even as backhaul. This is one of obstacles to reduce the distribution cost. Most of the distributions are done by trucks. Due to the fleet limitation, in some peak season, the delivery in some cities are delayed because their trucks have not returned from other delivery completion. The company want to test a strategy to maintain the number of standby trucks at the depot. This strategy is called "transfer trip". We aim to make a general model for long-haul distribution and truck driver scheduling with transfer trip. So that this model can be used for general applicability.

The basic of this model is the Vehicle Routing Problem (VRP) combine with Truck Driver Scheduling Problem (TDSP). We adopt the transfer strategy in here as a coverage problem, so that the trucks will allow to serve the route within a maximum driving time. The delivery for distant cities will be transfer to the other trucks that have been assigned to cover destination cities. We also take time windows and government driving regulations into consideration.

Literature Review

Several studies have been conducted to solve TDSP with working hour restriction and routing decision. To optimize maximum shift time limit for drivers, Campbell and Savelsbergh (2004) have developed a modified insertion heuristic. Goel (2009) developed algorithms considering the EU or US regulations. He focused at basic provision of EU regulation and solved a modified Solomon (1987) test instances for the VRPTW using large neighbourhood search algorithm. Prescott-Gagnon et al. (2010) developed alternatives EU provisions that were not considered in Goel (2009). They proposed a large neighbourhood search algorithm based on column generation heuristic. To generate routes (column) and a labelling algorithm for checking the feasibility, they used Tabu Search. Goel (2010) proposed breadth-first search (BFS) approach that always find the feasible solution. These methods still work separately with local search based optimisation methods for combined vehicle routing and truck driver scheduling.

Goel and Rousseau (2011) developed driver scheduling problem under Canadian regulation which is more permissive than US. He proposed two heuristics and an exact approach to solve the problem. Continue with truck driver scheduling problem, Goel et al. (2012) then developed the Australian-TDSP for the standard and Basic Fatigue Management Rules. The exact model and four heuristics approach are proposed to solve the problem during the reasonable computational time. Drexel et al. (2013) modelled the vehicle routing and driver scheduling simultaneously for long-haul trip in Europe. In this research, the drivers are not dedicated to the trucks. This offers greater planning flexibility and allows a better utilization of trucks, but also creates intricate interdependencies between trucks and drivers and requires the synchronization of their routes. Drexel et al. (2013) developed heuristic approach based on a two-stage decomposition. The study for long-haul vehicle routing and scheduling with HOS was also conducted by Rancourt et al. (2013). This research implemented US regulations and some alternative provisions of this regulations. To develop the problem, Rancourt et al. (2013) also took into account multiple time windows and heterogenous fleet constraints. Several scheduling algorithms embedded within a tabu search heuristic have been developed to solve the problem. The solution methods have been tested using modified Solomon instances. Koç et al. (2016) focused in evaluating idling options that often used by drivers. Here, the idling options that will be evaluated are keeping the vehicle engine running while the vehicle is not moving, resting at an Electrified Parking Space (EPS) or using an Auxiliary Power Unit (APU) while idling. To evaluate these three options, a mathematical model with the sum of driving cost, fuel cost, and idling cost as objective function. By looking the literatures of simultaneous vehicle routing and truck driver scheduling problem, there is no literature that discusses the transfer shipment between vehicles to avoid long-haul trip.

Scientific Contribution

The problem considered in this paper differs from the above-mentioned authors. In this research, we considered the following contributions:

- a. One truck can only deliver for one destination because the nature of cement shipment that always bigger than truck capacity.
- b. Using multiple time windows, we also consider transfer time as a time window. It means the transfer activity can only be done if two vehicles meet at the same point at the same window time.
- c. To maintain the number of trucks that standby in depot, we develop several transfer options strategies.
- d. The problem is developed to comply with Indonesian regulations that related with commercial vehicles.

The Truck Driver Scheduling Problem with Transfer Option Strategy (TDSPT)

Notations

We develop the model from Goel (2012) by adding the transfer constraints. In this model, a truck driver should deliver product from plant to customer location as scheduled. At each location $i \in n$ some loading or unloading work w_i shall be done. Every location has time windows that denoted by T_i and at each τ shall be include the $[t_{i,\tau}^{min}, t_{i,\tau}^{max}]$ range. The driving time from location i to $i+1$ denoted by $d_{i,i+1}$. The time horizon, which is 8 days, denoted by $t^{horizon}$.

Objectives

In this research, we want to minimize the total cost that is described by total travel duration. The longer the travel, distribution cost and driver cost will be higher. Let X^{end} be the ending time of a trip and x^{start} be the starting time before the trip begin. The objective function is denoted by this function below.

$$\sum_{i=1}^n x_i^{end} - x_i^{start} \quad (1)$$

Constraints

The constraints in this model are divided into 4 categories, which are time setting constraints, time windows constraints, HOS regulation constraints, and transfer constraints.

- a. Time Setting Constraints

$$x_i^{arrival} + \sum_{r \in R} t^r z_{i,r} \leq x_i^{start} \quad \text{for all } 1 \leq i \leq n \quad (2)$$

$$x_i^{start} + w_i = x_i^{end} \quad \text{for all } 1 \leq i \leq n \quad (3)$$

$$x_i^{end} + d_{i,i+1} = x_{i+1}^{arrival} \quad \text{for all } 1 \leq i \leq n \quad (4)$$

Constraint (2) restricts the work at any location must not start before the arrival plus any rest time. Constraint (3) set the work at any location i end w_i time units after it starts. Constraint (4) set the arrival at a location equals the end time of previous location plus the required driving time.

- b. Time Windows Constraints

$$y_{i,\tau} t_{i,\tau}^{min} \leq x_i^{start} \quad \text{for all } 1 \leq i \leq n, 1 \leq \tau \leq T_i \quad (5)$$

$$x_i^{start} \leq t^{horizon} - y_{i,\tau} (t^{horizon} - t_{i,\tau}^{max}) \quad \text{for all } 1 \leq i \leq T_i \quad (6)$$

We use different time windows for each city. Constraint (5) and (6) are the time windows constraint, the loading or unloading will start if the trucks arrive at the warehouse during within time windows.

c. HOS Regulation Constraints

In this paper, we consider the HOS regulations for traffic and road transports (Constitution no. 22 year 2009). We use terminologies in Rancourt et al. (2013), that described below:

Driving: Driving time is the total time spent at the driving controls of a commercial vehicle in operation, even when the vehicle is stuck in a traffic jam

On-duty: On-duty time means all the time a driver is performing work for any employer or is required to be available for work.

Off-duty: Drivers have no obligation to perform any work in off-duty time. They can leave the place where the vehicle is parked.

Sleeper berth: The time when driver is in the sleeper berth of a commercial vehicle in conformity with specific requirements.

Indonesia apply almost the same HOS rules as US. These regulations limit the driving and on duty time so that the drivers are not permitted to drive without resting. The regulations that should be conformed in driver scheduling are:

- Driver cannot drive after 70 hours on-duty during a week
- Driver may only drive maximum 8 hours or 12 hours (at certain situation) after 10 consecutive hours off-duty, including 1-hour rest
- A driver should take a break for $\frac{1}{2}$ - 1 hour after 4 hours driving

According to the HOS regulation, we can set the parameters as follows:

$h^{\text{total_duty}}$ = 70 hours, the maximum cumulated on-duty hours during a week

h^{rest} = 10 hours, the minimal duration of a rest period to regain driving time

h^{drive} = 12 hours, the maximum cumulated driving hours between two rest periods

$h^{\text{on_duty}}$ = 14 hours, the maximum cumulated on-duty hours. After this, the driver is illegal to drive without resting

$h^{\text{long_berth}}$ = 8 hours, the minimal duration of a long rest split period when a rest is split in conformity with the sleeper berth provision

$h^{\text{short_berth}}$ = 1 hours, the minimal duration of a short rest split period when a rest is split in conformity with the sleeper berth provision

Since it is a direct shipment, the truck drivers are required to drive back to the plant (depot) after delivering product. The trucks will be empty during travel back to the depot. We suppose the driver has been off-duty for a period at least 34 consecutive hours before leaving the depot.

$$x_k^{\text{arrival}} - x_i^{\text{start}} \leq t^c + t^{\text{horizon}} \sum_{j=i+1}^{k-1} \sum_{r \in R^c} Z_{j,r} \quad \text{for all } 1 \leq i < k \leq n; d_{k-1,k} > 0, c \in C1 \quad (7)$$

$$x_k^{\text{end}} - x_i^{\text{start}} \leq t^c + t^{\text{horizon}} \sum_{j=i+1}^k \sum_{r \in R^c} Z_{j,r} \quad \text{for all } 1 \leq i < k \leq n; w_k > 0, c \in C2 \quad (8)$$

$$\sum_{j=1}^{k-1} d_{j,j+1} + \delta^c \sum_{j=1}^{k-1} w_j \leq t^c + t^{\text{horizon}} \sum_{j=i+1}^{k-1} \sum_{r \in R^c} Z_{j,r} \quad (9)$$

for all $1 \leq i < k \leq n; d_{k-1,k} > 0, c \in C3$

$$\sum_{j=1}^{k-1} d_{j,j+1} + \delta^c \sum_{j=1}^k w_j \leq t^c + t^{\text{horizon}} \sum_{j=i+1}^k \sum_{r \in R^c} Z_{j,r} \quad (10)$$

for all $1 \leq i < k \leq n; w_k > 0, c \in C4$

This the general constraint of the HOS regulations. Constraints (7) and (8) set the time elapsed since the end of the last rest R^c is within the limits imposed by the constraints $c \in C1$ and $c \in C2$. Constraints (9) and (10) set the accumulated amount of driving and working without rest does not exceed the limits $c \in C3$ and $c \in C4$.

d. Transfer Constraints

This constraint keeps the cumulative of x^{end} from the previous visit and driving time of a truck cannot exceed the required arrival time at each i , this will set the long-distance trip will be transfer to another truck.

$$x_{i-1}^{end} + d_{i-1,i} \leq arrival_i^{limit} \quad \text{for all } 1 \leq i \leq n \quad (11)$$

Numerical Experiment

Here we want to use the developed model to solve small instance of cement distribution case study in Java Island. The company has a plant in Tuban. To optimize the distribution to western Java, company also has a packing plant in Ciwandan that has responsibilities to pack the bulk products and distribute it to several areas located near the packing plant. We will make schedule for 7 days deliveries. Figure 1 describes the distribution network in Java. The distribution to cities can be done both from central plant in Tuban or from packing plant in Ciwandan depend on the cheapest distribution cost and availability of stocks and vehicles. So, this problem can be categorized as multi depot-VRP. Table 1 will present the driving time to each city, exclude the idle and on duty time.

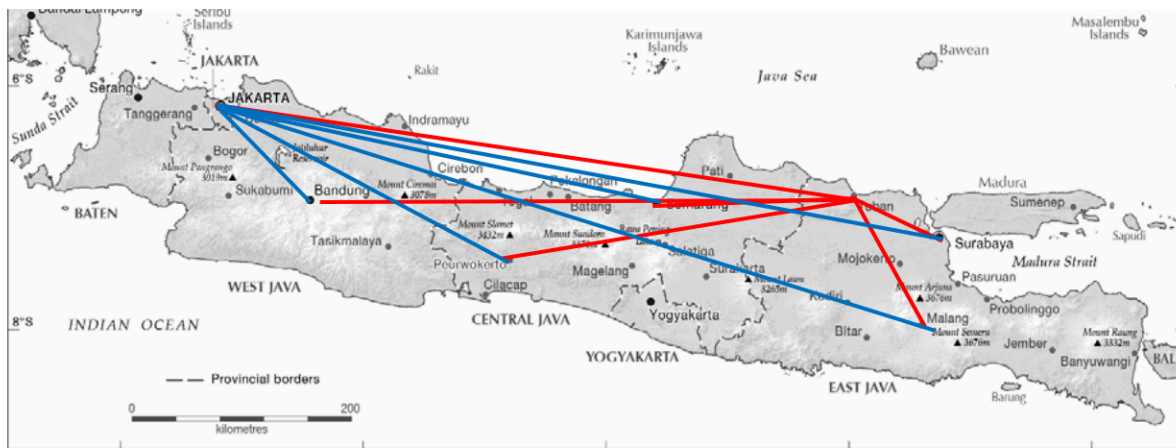


Figure 1. The Distribution Network in Java

From/To	Tuban	Ciwandan	Bandung	Purwokerto	Semarang	Surabaya	Malang
Tuban	0	11.5	11	7	5	3	5
Ciwandan		0	3	6	8	13	15

Table 1. Driving Time (hrs) to each City

Assumed the central plant only has 9 vehicles with 12-ton capacity. The company should make deliveries within a week as described in Table 2. To make deliveries, the company should ensure the number of available trucks as required. If the trucks are not available at the needed time, then on the previous trip there should be transferred shipment, so that the truck back to the factory just in time. The company should make deliveries with minimum total cost, which represent by total driving time.

Cities	Delivery Schedule (ton)						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Ciwandan		60					
Bandung			10			10	10
Purwokerto	20					10	
Semarang		10		30		10	
Surabaya		20	20			20	20
Malang	20				20		

Cities	Delivery Schedule (ton)						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Total truck needed (unit)	4	8	3	3	2	5	3

Table 2. Delivery Schedules to each City

Following the model, we solved the problem by using the developed algorithm. In the above problem, the required transfer doesn't occur because the number of owned trucks are more than required. We can see the schedule of trucks from Tuban plant in Table 3 and from Ciwandan plant in Table 4. For each schedule, the drivers experience several activities, such as driving, on-duty, and off-duty. The duration of each activity is set so that the HOS regulations are fulfilled. Figure 2 and 3 shows the detail activities of each driver. For example, driver 1 in that planning horizon should work 24 hours, including 10 hours off-duty, 10 hours driving, total 12 hours on-duty and 2 hours short rest. At figure 3, the off-duty that should be taken after maximum driving period is fulfilled by applying 8 hours long berth. In this experiment, there is no regulation that has been violated.

From Tuban	Schedule per Day							Total on-duty
Truck	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
Truck 1	24 hrs	8	8					30
Truck 2	24 hrs	8	8					30
Truck 3		37 hrs		24 hrs	24 hrs	24 hrs		71
Truck 4		37 hrs		24 hrs	24 hrs	8	8	73
Truck 5		37 hrs		24 hrs		8	8	59
Truck 6		37 hrs						29
Truck 7		37 hrs						29
Truck 8		24 hrs						14
Truck 9								0

Table 3. Driver Schedules from Tuban Plant

From Ciwandan	Schedule per Day							Total on-duty
Truck	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
Truck 1	26 hrs		8			8	8	40
Truck 2	26 hrs					26 hrs		32

Table 4. Driver Schedules from Ciwandan Plant

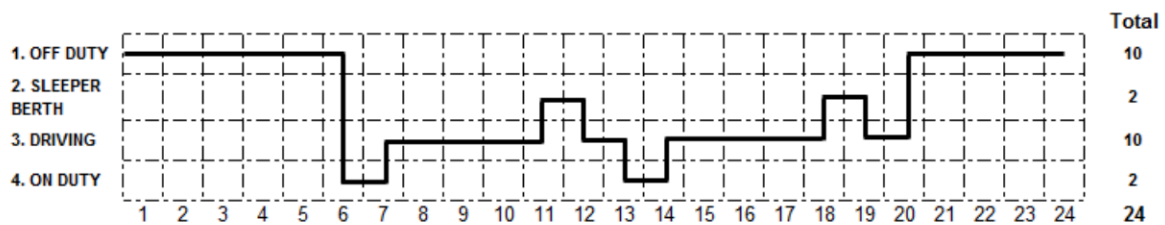


Figure 2. Detailed Schedule of Driver 1 & 2 From Tuban on Sunday

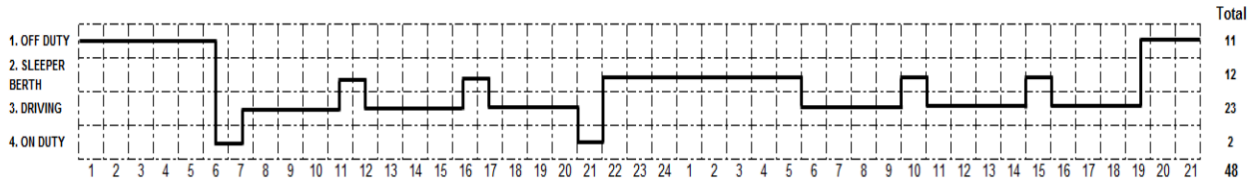


Figure 3. Detailed Schedule of Driver 3-7 From Tuban on Monday

Because the number of trucks in experiment 1 are still bigger than requirement, in the next experiment we will reduce the number of available trucks from 9 to 5. We want to see the effect of transfer constraint to the schedule. First, we change the delivery schedule as shown in Table 5.

Cities	Delivery Schedule (ton)						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Ciwandan		60					
Bandung			10			10	10
Purwokerto	20					10	
Semarang				30		10	
Surabaya			20			20	20
Malang					20		
Total truck needed (unit)	2	5	3	3	2	5	3

Table 5. Delivery Schedule of The Second Experiment

From the delivery schedule above, we generate schedule for drivers in Tuban and Ciwandan Plants. From the schedule that shown in Table 6, Truck 1 and Truck 2 from Tuban plant have to be transferred to trucks from Ciwandan plant. It is because the actual trip requires 2 days long, but unfortunately on the next day Tuban plant needs 2 trucks to deliver products to Surabaya. So the 2 trucks that have departed to Ciwandan have to be back to Tuban before delivery time. The delivery to Ciwandan will be continued by trucks from Ciwandan plant that have been arrived in transfer location before the transfer time. It is known that trucks from Ciwandan plant must travel 3.5 hours to the transfer point.

From Tuban	Schedule per Day							Total on-duty
Truck	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
Truck 1		30 hrs	8	24 hrs	24 hrs	24 hrs		
Truck 2		30 hrs	8	24 hrs	24 hrs	8	8	
Truck 3		37 hrs		24 hrs		8	8	
Truck 4		37 hrs						
Truck 5		37 hrs						

Table 6. Driver Schedules from Tuban Plant

From Ciwandan	Schedule per Day							Total on-duty
Truck	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	
Truck 1	26 hrs		9	16 hrs		8	8	40
Truck 2	26 hrs		9			26 hrs		32

Table 7. Driver Schedules from Ciwandan Plant

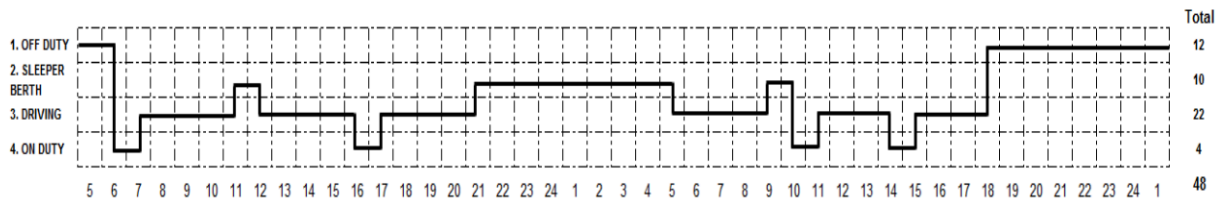


Figure 4. Detailed Schedule of Driver 1 & 2 From Tuban on Monday-Tuesday

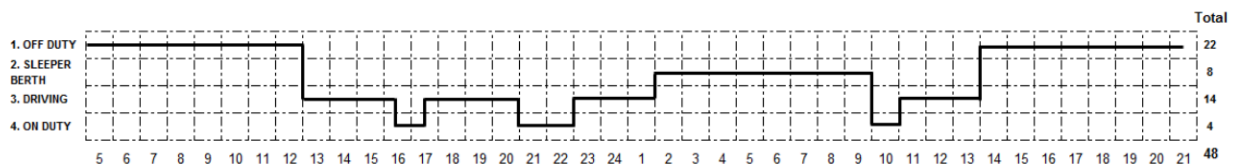


Figure 5. Detailed Schedule of Driver 1 & 2 From Ciwandan on Monday-Tuesday

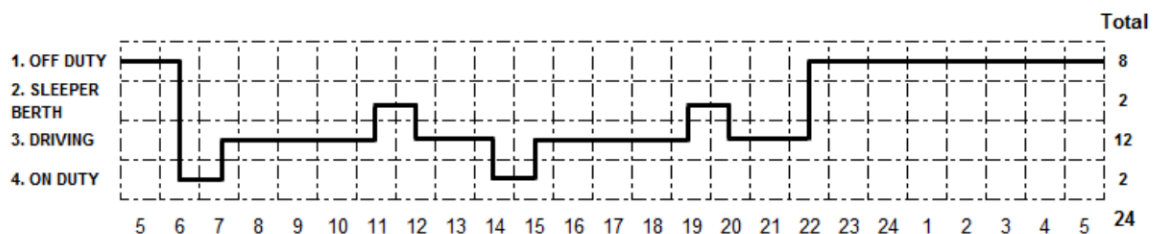


Figure 6. Detailed Schedule of Driver 1 & 2 From Ciwandan on Sunday

Process of transferring shipment from trucks of Tuban plant to the trucks of Ciwandan plant occur at 4 pm in Monday. After that, both trucks travel back to each original location. Trucks from Tuban plant have to take long berth in order to cope with HOS rules. Figure 5 show us that when truck 1 from Ciwandan plant arrive at it's second destination in Bandung, the warehouse has already close (time windows), so the truck should wait until the operational time of warehouse. During the waiting, the truck driver takes a long berth at destination warehouse.

Conclusion

We have developed a new transferring method in simultaneous vehicle routing and truck driver delivery problem. This research implements the HOS rules in Indonesia. Due to the scarcity of the vehicles, the vehicles should be at the plant at required time. So that the delivery to other cities won't be delayed. A mixed integer programming has been developed to solve the experiments. The objective function in the model is minimising the total delivery duration, following with 4 types of constraints. From the conducted experiments, we can conclude that the developed model can achieve the objective function while fulfilling the constraints.

In the future, we want to observe different transfer methods and employed multimode transportation such as train to make distribution more efisien.

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