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The Open Vehicle Routing Problem With Time Windows Considering Driver's Working Hour

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***Abstract*: This paper presents an optimization model for a logistic management called open vehicle routing problem with time windows with driver's working time (OVRPTWWDWT). This is an extension of the classical OVRPTW which considers driver's working time to model the scheduling of the available drivers with respect of the driving time to satisfy customers' demand. The objective is to schedule the delivery according to the driver's working time and to determine the fleet scheduling and the driver's policy in serving the customer, such that to minimize the amount of cost over all the routes within the planning horizon. We propose a tabu search heuristic algorithms approach to solve the problem.**
***Keywords*: Vehicle Routing Problem with Time Windows, Logistics, Working Time, Tabu search, Integer programming**

I. INTRODUCTION

The consideration of the driver's working time in the issue of vehicle routing is a very aspect so as to improve the safety and spending time of transporting and distributing goods. According to the regulations for the working hours of drivers in Indonesia provided in article 90 of Law no. 22 Year 2009, regarding the working time of the driver and this provision aims to focus the driver's concentration of driving for the safety of goods and other road users. The company must have a plan to manage the driver's working time in such a way that the driver obeys the established rules. Punctuality of delivery and pick up of goods can be fulfilled if the planned vehicle route sees all operational constraints, in particular the driver's working time limitation. Most literature deals with the route and scheduling of vehicles but ignores the regulation of the driver's working hours.

This paper discusses a special variant of VRPTW ([1]) called Open VRP with time windows (OVRPTW) ([2]). The OVRPTW, which considers the labor management decision to use the driver in the most profitable way known as OVRPTW with drivers' working time (OVRPTWWDWT), creates a route planning model aimed at producing an efficient route. It is assumed that each customer request is known when the delivery schedule is determined, such as the distance and travel time between the depots and the location of each customer are minimized. In addition, the interval time at which delivery is to be made and this interval is limited by the start and end time at which certain customers can be served.

Thus, OVRTWWDWT for serving customers' demand is modelled by considering the travel time and working time of the driver to produce an efficient overall the routing of vehicles used.

II. RELATED WORK

In managing delivery for goods distribution, effective route planning techniques are commonly known as vehicle routing problems ([3]). The problem of vehicle routing with time windows (VRPTW) is one of the most widely studied and researched VRP variants with published papers, including ([4]-[7]) provides a comprehensive overview of the precise and heuristic methods for VRPTW. ([5]) provide an overview and advanced heuristic analysis to solve large-scale VRPTW.

A survey of algorithms was given by [6]. The best metaheuristics for solving current VRPTW are the picking algorithms ([8], [9]) , large neighborhood search ([10]-[12]), and local search iteration ([13]). Real-world applications can be found for OVRP and OVRPTW are rail transport, bus and air ([14]-[17]).

The OVRPTW includes three types of sub-problems namely 1). Shipping, where the vehicle is towards delivery without having to return to the company's distribution center; 2) Pickup, where the vehicle is necessarily to take a route that starts directly from the customer at the other end of the route and ends at the depot; (3) Delivery and pick-up, where upon completion of all shipments, the vehicle returns to the customer's existing depot on order and picks up the items to be sent to the center, or after completion all pick-ups can be back to the depot through pick-up route and deliver the demands to the customer in reverse order. In the case of shipping and picking up, it is necessary to limit the working time of the driver, in which the amount of working hours of the driver must be correspondence to the capacity.

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There are some of research findings that address work-time issues and have to take a break every day before boarding the plane, (e.g. [18]) collect successors to solve the dynamic and common delivery and pickup problems where lunch breaks and dinner breaks should be made in fixed time intervals; (e.g. [19]) presents an approach to solve pickup and delivery problems by specifying the work time of the package driver by the U.S. Transportation and approximately daily breaks can be taken before the maximum daily driving time is up.

III.DRIVER'S WORKING TIME

The working hours regulations for drivers in Indonesia are regulated in Law no. 22 of 2009 on article 90, concerning working hours, rest periods, and rest periods for drivers who make land transportation of goods and passengers. The driver's working hours regulations are arranged in a way that the driver must obey the rules and take the responsibility for any violations committed by the driver. The rules are:

A. Each Public Transport Company shall obey and enforce provisions concerning with the working hours, rest periods and changes of the General Motor Vehicle Drivers in accordance with the provisions of the laws and constitutions.
B. Working time for driver shall not exceed 8(eight) hours a day.
C. Motor Vehicle Drivers General after driving the vehicles for 4 (four) consecutive hours shall rest at least half hour.
D. In certain cases the driver may be employed no later than 12 (twelve) hours a day including 1 (one) hour rest period.

Figures 1 and 2 illustrate examples of working time and rest periods for vehicles using two drivers. In a double-wheeled vehicle, one driver may rest while the second driver drives.

Driving	Rest	Driving	Other Activities	Working time
4h	1h	4h	3h	12h

Fig 1. Driving and Resting Time

Driver 1

Driving	Rest	Driving	Rest	Other Activities	Working time
4h	30m	4h	30m	3h	12h

Driver 2

Rest	Driving	Rest	Driving	Other Activities	Working time
4h	30m	4h	30m	3h	12h

Fig 2. Driving and Resting Time

IV.THE OPEN VEHICLE ROUTING PROBLEM WITH WINDOS TIME

The open vehicle routing problems are a problem faced by companies that have absolutely no fleet of vehicles, or their fleets are inadequate to meet customer demand (e.g. [15]). Therefore, the company must contract all or part of the vehicle for shipping or pick-up to an external operator. Furthermore, when the company has its own fleet and is insufficient to meet customer demands varying from time to time, the OVRPTW provides the right combination of owned and leased vehicles. In such cases, renting a vehicle costs more per unit distance, but does not require maintenance costs ([16]).
The Real-world applications for OVRP and OVRPTW can be found on the issue of rail, bus and air transportation ([15]). ([20]) considers that the scheduling of vehicles to deliver food to school involves simultaneous uptake and delivery within a fixed time window, in which the vehicle performs an open route. Another researcher, ([21]) considers the train railway model for the British Rail transport service through Tunnel planning. The goal is to minimize the number of trains moving through tunnels, mileage and consider the capacity of trains and the boundaries of time windows through tunnels. The OVRP or OVRPTW is an NP-hard. OVRPTW includes three sub types of problems, including 1). Delivery, route of vehicle assigned to delivery without having to

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return to the company's distribution center; 2). Pick-up, route of vehicle assigned to pick-up and end at depot; 3). Shipping and pick up, after completing all shipments to the customer, the vehicle returns to the depot who visits the customer in reverse order and retrieves the items to be sent to the distribution center, or after the pick-up is complete, the vehicle returns to the depot by following pick-up route and delivering the goods to the customer in reverse order.

The OVRPTW with driver's working time is defined as a complete direct graph $G=(V,E)$ where $V=\{0,1,...,n\}$ is the set of nodes and $E=\{e\equiv(i,j): i\neq j\in V\}$ is the set of edge.. Node 0 is declared with depot and the other nodes are declared as customers. OVRPTWWDWT by indicating the working time planning for the driver (*T*) and driver's working day (*D*) declared as $T_l\subseteq T$ .The driver start and end time of the driver $l\in D$ on day $t\in T$ respectively as a_l^t and b_l^t . H shows the set of vehicles. For each vehicle $(h\in H)$ let's say q_h the capacity of the vehicle. We define the set of the number *n* customers as $N=\{1,2,...n\}$ and depot $\{0,n+1\}$. For each vehicle start from $\{0\}$ and ends $\{n+1\}$. The set for subscribers $i\in N$ that notify as $T_i\subseteq T$, where to serve customer demand d_i on day $t\in T_i$ requires service time duration and time window $[u_i,v_i]$. The total time to travel from node *i* to node *j* is denoted by t_{ij} .

The formulation for OVRPTWWDWT can be explained mathematically as follows :

A. Variables

x_{ijh}^t	(1) variable indicating vehicle departing from node *i* to node j on day $t\in T$ or otherwise (0)
y_{lh}^t	(1) variable indicating vehicle *h* assigned to the driver $l\in D$ on day $t\in T$ or otherwise (0)
z_{ih}^t	(1) variable indicating vehicle *h* break after serving node i on day $t\in T$ or otherwise (0)
u_{ih}^t	(1) variable to indicate that the vehicle's leisure time *h* on the node *i* after having a break on day $t\in T$ or otherwise (0)

B. Sets

D	The set of driver's
T	The set of workdays planning
T_l	The set of driver's work day $l\in D$
T_i	The set of days for customer $i\in N$ orders
N	The set of customers
N_0	The set of the combining customer's node and center $N_0=\{0,n+1\}\cup N$
H	The fleet of vehicles $h\in H$

C. Parameter

C_1	Travel cost from customer *i* to customer *j* by vehicle *h*
C_2	The cost of regular labor for vehicle *h* per unit time
C_3	Overtime driver's cost for vehicles *h* per unit time
d_i^t	Demand of node *i* on day $t\in T_i$
q_h	Capacity of vehicles *h*
A	The maximum working time for each driver
U	The time limit is tied to the driving of each driver
P_h^t	The Maximum Route Time allowed for vehicle *h* on day $t\in T_i$
S_{ih}^t	Service time vehicle *h* from node i on day $t\in T_i$

R_l^t The total working of driver $l \in D$ on day $t \in T$

$[u_i, v_i]$ The interval of visit time that customer can be serviced by any vehicle at node $i \in N_0$

$[a_l^t, b_l^t]$ The interval from the start to the end of time of driver $l \in D$ on day $t \in T$

X_l^t Overtime of driver $l \in D$ on day $t \in T$

Y_i^t Waiting time from node i on day $t \in T_i$

Z_i^t Arrival time from i on day $t \in T_i$

I_i^t Departure time to node i on day $t \in T_i$

W_{0h}^t Arrival time vehicle h from depot on day $t \in T_i$

m_l^t The total travel of driver $l \in D$ on day $t \in T$

t_{ij} The total travel time from node i to node j

Furthermore, a vehicle is considered as the driver's working time when it services customer. Given the above-defined variables and parameters, the problem can be formulated for OVRPTWWDWT as follows :

D. Objective Function

$$\min \; C_1 \sum_{h\in H}\sum_{i\in N_0}\sum_{j\in N_0}\sum_{t\in T_i} t_{ij} x_{ijh}^t + C_2 \sum_{l\in D}\sum_{t\in T_i} m_l^t (W_{0h}^t - X_l^t) + C_3 \sum_{l\in D}\sum_{t\in T_i} X_l^t \qquad (1)$$

E. Subject to

$$\sum_{h\in H}\sum_{j\in N_0} x_{ijh}^t = 1, \quad for\ i \in N, t \in T_i \qquad (2)$$

$$\sum_{h\in H}\sum_{i\in N_0} x_{ijh}^t = 1, \quad for\ j \in N, t \in T_i \qquad (3)$$

$$x_{ijh}^t \le y_{lh}^t, \quad l \in D,\ t \in T_i \qquad (4)$$

$$\sum_{i\in N}\sum_{j\in N_0} d_i^t x_{ijh}^t \le q_h, \quad for\ h \in H,\ t \in T \qquad (5)$$

$$u_{jh}^t \ge u_{ih}^t + t_{ij} - M(1 - x_{ijh}^t) - M z_{ih}^t, \quad i, j \in No,\ h \in H,\ t \in T \qquad (6)$$

$$u_{jh}^t \ge t_{ij} - M(1 - x_{ijh}^t), \quad i, j \in N,\ h \in H,\ t \in T \qquad (7)$$

$$P_h^t \ge W_{0h}^t \ge Z_i^t + S_i^t + Y_i^t + t_{i0} + M(x_{i0h}^t - 1), \quad for\ h \in H,\ i \in N \qquad (8)$$

$$\sum_{i\in N_0}\sum_{j\in N_0} t_{ij} x_{ijh}^t \le U, \quad for\ h \in H \qquad (9)$$

$$\sum_{i\in N_0}\sum_{j\in N_0} (t_{ij} + S_i^t) x_{ijh}^t \le R, \quad for\ h \in \{1,.....H\} \qquad (10)$$

$$\sum_{t\in T_i} R_l^t \le A, \quad for\ l \in D \qquad (11)$$

$$I_i^t \le Z_i^t - S_{ih}^t, \quad for\ i \in N_0,\ h \in H,\ t \in T_i \qquad (12)$$

$$u_i \le S_{ih}^t \le v_i, \quad for\ i \in N_0,\ h \in H,\ t \in T_i \qquad (13)$$

$$x_{ij}^h = \{0,1\}, \quad for\ i, j \in \{1,.....,V\}; \quad h \in \{1,.....H\} \qquad (14)$$

The expression (1) is to minimize overall total travel cost, the amount of the driver's working costs set for regular time and overtime costs. Equations (2) and (3) are to ensure that one and only one vehicle enters and departs from each customer as well as the depot..

Constraint (4) ensure that each vehicle is assigned to a particular driver to serve customers. Constraint (5) states the capacity of each vehicle should not exceed the total customers' demand. Equations (6) and (7) determine the driving time that has passed, where for vehicle *h* travelling from customer *i* to *j* on *t* day, the driving time passed is equal to the driving time passed by plus time driving from *i* to *j* ($u^t_{jh} \geq u^t_{ih} + t_{ij}$) if the vehicle does not rest on the customer $i(z^t_{ih} = 0)$; others, if the vehicle takes a break on the customer $i(z^t_{ih} = 1)$, the driving time elapsed in *j* will be ascertained greater than or equal to the travel time between *i* and *j* ($u^t_{jh} \geq t_{ij}$). Expression (8) ensure the timing of arrival and determining the time window of the vehicle to the customer. Expressions (9) and (10) ensure that the driving time of each driver can not exceed the upper limit of each driver's working time per day. Constraint (11) ensure that the driver works no more than the maximum duration of work. Constraints (12) and (13) ensure that there is a relationship between arrival time, departure time, and service time with customer *i* in accordance with the customer's time window.

V. TABU SEARCH HEURISTIC

Tabu Search (TS) is a local search metaheuristic introduced by [22]. Tabu search explores the solution space by moving at each iteration, from solution *x* to the best solution in a subset neighbourhood *N(x)*. Tabu search manages a memory of the solutions or moves recently applied, which is called the tabu list. This tabu list constitutes the short-term memory. At each iteration of TS, the short-term memory is updated. Storing all visited solutions is time and space consuming. Indeed, we have to check at each iteration if a generated solution does not belong to the list of all visited solutions

The aspiration criterion happens for example when tabu solution is better than any previously seen solution and also various techniques are often employed to diversify or to intensify the search process. The main idea underlying this method is the generalization of traditional insertion in order to avoid constructing too many short routes. The problem becomes then of deciding a route for the vehicle (starting and ending at given locations) such that is visits some of customers. Customers not visited can either be allocated to a customer on the vehicle route or can be isolated.

Any implementation of tabu search requires initial solution generation and a neigbourhood search procedure. To solve the OVRPTWWDWT problem, these are implemented as follows :

A. Step 1 : Intial solution generation. Choose an initial solution *i* in *x*. Set *i** = *i* and *k* = 0
B. Step 2 : Set *k* = *k* + 1 and generate a subset *V** of solution in *N* (*i*,*k*) such that either one of the Tabu conditions is violated or at least one of the aspiration conditions holds.
C. Step 3 : Choose a best j in *i** and set *i* = *j*
D. Step 4 : If *f*(*i*) < *f*(*i**) then set *i** = *i*
E. Step 5 : Update Tabu and aspiration conditions
F. Step 6 : If a stopping condition is met then stop.
G. Else go to Step 2.

The algorithm sequentially opens routes and fills them with customers according to specific criteria until no more customers can be feasibly inserted. To open a new route, the procedure selects the unrouted customer farthest from the depot and generates a new route. In the next step, for each of the still unrouted customers unrouted the best insertion position between two consecutive customers is determined according to criterion. These steps are repeated as long as a customer can be inserted into the route without violating constraints. If this is no longer possible, the route is closed, added to the solution *x* and the procedure continues with the next route until either routes are created or each customer is routed. After routes have been created, any customers that are still unrouted are added to the routes at the best insertion position according to the generalized cost function.

VI. CONCLUSION

This paper was intended to present a solution for OVRPTWWDWT, a route planning problem that integrates different extents of available driver knowledge by means of drivers working times. The aim of this paper was to develop a model of Open Vehicle Routing Problem Time Windows with Driver's Working Time. We present a mathematical model of OVRPTWWDWT as met heuristic solution method. After a pre-processing step removing infeasible arcs, an initial solution is generated by means of a sequential insertion heuristic. This problem has additional constraint is the driver's working time window handling variables.

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