resources should be allocated to the damaged roads as soon as possible for recovery. Therefore, the first category is urgent relief supplies distribution. Garrido et al. (2015) presented a stochastic programming to optimize inventory levels for emergency supplies and vehicles' availability to deliver enough supplies to satisfy demands with a given probability. Huang et al. (2015) developed a multi-objective optimization model that combines resource allocation with emergency distribution, where a ~~time space~~time-space network is used to incorporate the frequent information and decision updates in a rolling horizon approach. Pradhananga et al. (2016) proposed a three-echelon network model for integrated emergency preparedness and response planning for the distribution of emergency supplies. Post-disaster road recovery involves emergency resources allocation.

Another category is post-disaster recovery. Hu and Sheu (2013) developed a multi-objective model for post-disaster debris reverse logistics. Liberatore et al. (2014) proposed a multi-criteria optimization model for recovery of damaged elements of the distribution network, so that the consequent distribution planning would be beneficial. Moreover, there are lots of research which present ~~algorithm~~ algorithms for solving mixed-integer programming model (Cui et al. 2012, 2013; Kang et al. 2014, 2016; Xue et al. 2015).

The third category is studies on value of ~~time. The~~time and the increase of travel time due to variations in the traffic conditions, and including predictable variations (~~e.g.~~ e.g., peak-hour congestion), and unpredictable variations (~~e.g.~~e.g., vehicular crashes). In transportation research, the morning peak-hour congestion is considered ~~as~~ to be a classic problem of trip scheduling under deterministic traffic conditions (Carrion and Levinson, 2012). The peak-hour congestion is considered as a classic problem of trip scheduling under deterministic or uncertain traffic conditions (Coulombela and Palma, 2014). The unpredictable ~~variations~~ variations of delayed travel time ~~has~~ have been divided ~~in~~ into three elements by Wong and Sussman (1973): variation between seasons and days of the week; variation by changes in travel conditions because of weather and crashes or incidents; and variations attributed to each traveller's perception. Börjesson and Eliasson (2014) studied experiences from the Swedish Value of Time, and results show that the value of time varies both with traveller characteristics (income, having children, employment, living in Stockholm) and with trip characteristics (travel mode, travel time, travel ~~cost~~ cost, and travel purpose).

The most significant contributions of this paper to the literature are as follows. (1) ~~An~~ A UWD can not only cause loss of property and damage of environment, but ~~same~~ just as important~~ly~~, value of the delay to travellers can be affected, which are considered in the formulation of road recovery. To the best of our knowledge, none of the prior ~~researches~~ research studied the value of time due to delay of road recovery. (2) As a holistic consideration, a mixed-integer programming model is proposed with the objectives of minimizing economic costs and value of delay. Their ~~tradeoffs~~ trade-offs are studied according to the simple quantification for value of delay. (3) The impacts of duration of UWD on value of delay to travellers are studied to make our work ~~closer to~~more closely resemble the real situation.

The paper proposes a road recovery planning approach that aims at efficiently ~~repair the affected roads~~repairing the roads affected by ~~UWD~~ a UWD and reducing the influence of the ~~UWD~~ UWD on traffic and ~~disaster-affected people.~~people affected by the disaster. Considering the estimation of water volume on road, collection, ~~assignment~~ assignment, and transportation of pumps after UWDs, the road recovery planning is formulated as a ~~mixed integer~~mixed-integer programming model. A ~~tradeoff~~ trade-off between economic costs (for collecting, ~~transporting~~ transporting, and holding pumps) and the value of delay to travellers around the UWD-affected roads ~~are~~ is studied. In reality, except for the time of road recovery, the value of delay ~~are~~ is affected by many other reasons. According to the investigations on emergency officials and related literature, the impacts of two factors (population density and duration) of UWDs on the value of delay to travellers are studied (Robinson and Kapo, 2004; Soremekun et al. 2011). A real-world example for Pudong district of Shanghai is used to demonstrate and verify the proposed method.

The paper is organized as follows. In Section 2, road recovery planning for UWDs is built, and a ~~mixed integer~~mixed-integer programming model is formulated. In Section 3, the tasks for input data acquisition and parameters estimation are elucidated. Then, numerical studies are described, and findings observed from these numerical results are summarized in Section 4. Managerial implications, and suggestions for future research, are summarized in Section 5.

2 Modelling

Figure 1 presents the overall structure of road recovery planning for UWDs. Due to rainfall intensity and capacity of rescue center ~~are variable with time goes on~~being variable at different times, this work considers dynamic recovery of roads by discrete the planning horizon into time steps. The decisions on estimation of water volume on the road, and pumps collection, ~~assignment~~ assignment, and transportation are dynamic ~~made~~ and made in each time step. The dynamic recovery problem is formulated as a mixed-integer programming model with objectives of minimizing economic costs and ~~total~~ the total value of delay. To facilitate model formulation, several assumptions are presented as follows. (1) Transportation time required for collecting or allocating pumps is short enough. (2) Traveller's path choice behavior is not studied in the model.

Figure 1 A methodological framework of road recovery planning for UWDs

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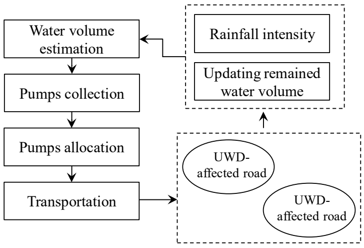

The set of UWD-affected roads is denoted by I, and indexed by $i \in I$. The set of rescue centers is denoted by K, and indexed by $k \in K$. Usually, each administrative area has one rescue center, and each rescue center is responsible for the first-line rescue operation in its ~~belonged~~ own administrative area. The set of time steps is denoted by T. A specific volume of water can be pumped in each time step $t \in T$. The pumping capacity is limited depending on ~~number~~ the number of pumps owned or collected by rescue centers. Pump might be collected from other places, when water volume ~~exceed~~ exceeds the pumping capacity of the rescue center. We discretize continuous number of pumps as quantity levels, indexed by $l \in L$. A quantity level represents a certain number of pumps that can be collected. ~~The higher quantity level is collected~~The higher the level of quantity that is collected means that a more specific number of pumps can be used. For example, 20 pumps are available if quantity level 1 is collected, and 40 pumps are available if quantity level 2 is collected. In such a situation, additional resource costs are involved.

The number of pumps can be collected at quantity level l, which is denoted by V_l. The duration length of each time step t is set to τ. The water volume on each road must be less than R at the end of time step ($|T|$). The initial water volume on road i is denoted by Q_i. According to the historical data, water volume for road i is denoted by B_i per time step when the rainfall intensity is E_i. Pumpage of a pump working for an hour is denoted by O. The rainfall intensity in time step t on road i is denoted as $\alpha_{t,i}$. The initial ~~amount~~ number of pumps in rescue center k is denoted as H_k. According to the distances from rescue centers to UWD-affected roads, tasks are allocated to each rescue center. If the rescue center k has responsibility for UWD-affected road i, $\Xi_{k,i}$ is one; otherwise, zero.

The cost for collecting quantity level l of pumps in time step t is denoted by $C_{t,l}^L$. The operational cost of a pump in time step t is denoted by C_t^O. The holding cost of a pump in time step t is denoted by C_t^H. This is intuitive, travel speed and number of affected travelers are respectively ~~depend~~ dependent on the inundated depths and areas, then cause costs of travel delay to travelers. The value of delay per unit (i.e. m^3) of water volume to travelers in time step t for road i is denoted as $G_{t,i}$. Note that unit value of delay is highly related to number of travelers. Finally, M is a big positive number.

Decision variables are described in the following. Incremental water volume at time step t on road i is denoted as $s_{t,i}$. The water volume at the end of time step t for road i is denoted as $d_{t,i}$. The drained water volume for road i by rescue center k in time step t is denoted as $x_{t,k,i}$. Define $y_{t,l}$, and if quantity level l of pumps is collected in time step t, $y_{k,l}=1$; otherwise, $y_{k,l}=0$. Number of pumps allocated to rescue center k in time step t is denoted as $z_{t,k}$. The ~~amount~~ number of pumps in rescue center k at time step t is denoted as $r_{t,k}$. Define $h_{t,k,i}$, and if the UWD-affected road i is repaired by rescue center k, $h_{t,k,i}=1$; otherwise, $h_{t,k,i}=0$.

Based on the above notations, a mixed-integer programming model is formulated for repairing UWD-affected roads with the goal of minimizing total economic cost and value of delay. The economic costs include resource cost (e^L), operational cost (e^O), and holding cost (e^H). The total value of delay is denoted as (e^R).

Operational cost (e^O) is a function of the following data: the drained water volume, the pumpage of a pump, the time span of each time step, and the unit operational cost, as defined in Eq. (2). Holding cost (e^H) is a function of the following data: the ~~remained~~ remaining pumps in rescue center and unit holding cost. Therefore, e^H is defined in Eq. (3).

Value of delay (e^R) is a function of the following data: the ~~remained~~ remaining water volume, the average of the drained water volume, and the unit value of delay, as defined in Eq. (4). Apparently, total value of delay is positive correlation with the ~~remained~~ remaining water volume. The ~~remained~~ remaining water volume ~~decline~~ declines with increasing number of pumps, so does the economic costs. Therefore, economic costs and total value of delay are conflicting with each other. Four equations (Eqs. (5) - (8)) aggregate Eqs. (1)-(4) into scalar values, respectively.

$$e_t^L = \sum_l \left(y_{t,l} \cdot C_{t,l}^L\right), \quad \forall t \tag{1}$$

$$e_t^O = \sum_{k,i} \left(\frac{x_{t,k,i}}{O \cdot \tau} \cdot C_t^O\right), \quad \forall t \tag{2}$$

$$e_t^H = \sum_k \left(\left(r_{t,k} - \frac{x_{t,k,i}}{O \cdot \tau} - H_k\right) \cdot C_t^H\right), \quad \forall t \tag{3}$$

$$e_t^R = \sum_{i \in I} \left(\left(d_{t,i} + x_{t,k,i}/2\right) \cdot G_{t,i}\right), \quad \forall t \tag{4}$$

$$e^L = \sum_t e_t^L \tag{5}$$

$$e^O = \sum_t e_t^O \tag{6}$$

$$e^H = \sum_t e_t^H \tag{7}$$

$$e^R = \sum_{t \in T} e_t^R \tag{8}$$

In each time step, at most one quantity level can be set (Eq. (9))~~).~~ ~~Because~~ because the decision-maker could ~~just~~ ~~make~~make just one decision in one time step. Certainly,

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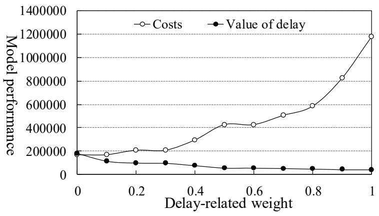

5 Conclusions

This work presents a road recovery planning to reduce the effects of ~~UWD~~ UWDs on travelers. A mixed-integer programming ~~model~~ model, with the goal of minimizing economic costs and value of ~~delay~~ delay, is developed. The road recovery approach involves the estimation of water volume on roads, and collection, ~~allocation~~ allocation, and transportation of pumps.

Some practical implications for road recovery of UWDs are found from numerical analysis. (1) The proposed approach that ~~consider~~ considers value of delay to travelers is particularly helpful for accelerating road recovery process. However, adequate ~~number~~ numbers of pumps must be stored in the rescue centers. (2) Negotiating for ~~cooperating~~ cooperation with related rescue entities (fire stations, armed police~~s~~, and related companies)~~,~~ ~~it~~ might be beneficial for increasing quick response, ~~collecting~~ collection, and dispatching of relief resources. (3) UWD-related information should be released, and backup trips should be scheduled for reducing value of delay.

As for future research directions, due to the limitations of data collection, and the lack of published research~~es~~ on sophisticated quantification methods for value of delay, new ways of data collection and ~~quantify~~ quantification of value of delay can be tried for improved results. Second, multi-sectors cooperation that affects the efficiency of recovery can be considered. Third, we suggest that the demands and transport time from rescue centers to UWD-affected roads are deterministic. In practice, these types of information may be uncertain and dynamic~~al~~. Therefore, when the study considers the uncertain and dynamic environments and uses the real-time traffic information and control, the applicability of the developed method can be strengthened.

Acknowledgements

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