Maintaining the transport system under extreme weather events: dual-network, behaviour and information

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Abstract: Recent years have seen an increase in the frequency of extreme weather events globally, and these have resulted in severe impacts on the transport system. to the means by which the transport system can be maintained under extreme weather events is an emerging topic in transport studies, and this is augmented by a growing concern about climate change. This paper considers transport system as dual-network composed of an interrelated operation level and management level that has some similarity with the theory behind the Wardrop Principle. The analysis is focused on collective behaviour in the operation network and activity in the management network. Relevant mathematical models are developed to operationalise the theoretical foundations. Interactions through the form of information communication and organisational collaboration within and between networks are highlighted. Evidence from the case study on the snow event in South China in early 2008 is used to test the model and conclusions are drawn on the need for further research. This paper contributes to a better understanding about the role of networks, collective behaviour and information interchange in influencing the maintenance of transport system under extreme weather conditions.

Keywords: transport system, climate change, extreme weather, management, dual-network, behaviour, information, mathematical model, case study, China

1. Introduction

Climate change has increased the likelihood of extreme weather phenomena, and these events refer to severe or unseasonal weather that are rare in the historical meteorological distribution, as they occur only 5% or less of the time (IPCC, 2001; IPCC, 2007; Zhu and Thot, 2001). Such extreme weather events are also known as “disasters.” But the difference between extreme weather and a disaster lies in the fact that a disaster is a broader concept that may include geophysical events (such as earthquakes), or an industrial accident (such as explosion in factory caused by unsafe act), and these events do not have a relationship with climate (Rosenzweig, 2011). In the just past year (2011), twelve extreme weather events occurred in the US, each costing more than $1 billion (Peralta, 2011).

The impacts of extreme weather on transport system may range from an increase in the discomfort to travellers to increase in the system vulnerability (Nagurney et al., 2010) and degradation of the transport system (Al-Deek and Emam, 2006). The disturbances to the transport system may further cause substantial economic and social strains and threaten life and health (Jenelius, 2009). The effects of extreme weather on transport system have been mainly mentioned in the context of network reliability and vulnerability, but not in the specific context of extreme weather conditions (Sumalee et al., 2011). Suarez et al. (2005) have noticed that "transport sector in general is not considering adaptation as a solution to these potential impacts".

Unlike most previous work that focused on transport network reliability and vulnerability, this paper considers the transport system as a dual-network composed of the operation level and the management level. Analysis is focused on networked behaviour and activities, and a case study about the snow event in early 2008 in South China is provided to illustrate the implication from the dual-network analysis. The information flow is highlighted in the model development and the case study.

2. Analysis of Dual-network Characteristics of Transport System

Transport system is a man-made complex system which has been constructed for people, vehicles, roads and other infrastructures. The human element has adaptability and it is the most active part of the system. Since the term "adaptation build complexity" (Holland, 1995) has emerged from the literature, the transport system can be seen as a kind of Complex Adaptive System (CAS). This system may emerge through two kinds of networks, that is, the operation network and the management network. This interpretation has some similarity with the two levels implied in the Wardrop principle (Wardrop, 1952) where traffic distribution optimization takes place at two levels, namely the user level and the system level (manager level).

This paper considers these two levels as a dual-network and it will focus on the network effects and the interrelations between networks. But, unlike the Wardrop theory, the dual-network has broader meanings. For the operation network, it covers all kinds of operating elements from infrastructures to vehicles and travellers. While at the management network, it covers the managers not only in transport sector but also in other related sectors. Transport emergency management under extreme weather events involves various information and resources that belong to not only transport sector but also other sectors. So the dual-network is more complex and involves more factors and actors than the two levels expressed in the Wardrop theory.

The dual-network can be defined as follows:

Let $G_m = (M, E_m)$ denote the operation network. Where, $M = (m_1, m_2, \cdots, m_n)$ denotes the set of elements; $E_m = \{(m_i, m_j)\}$, $i, j = 1,2,\cdots,n$, denotes the set of relations. Therefore, (m_i, m_j) denotes the connection or some interaction between the elements m_i and m_j.

Let $G_p = (P, E_p)$ denote the management network. Where, $P = \{p_1, p_2, \cdots, p_m\}$, denotes the set of managers; $E_p = \{(p_i, p_j)\}$, $i, j = 1,2,\cdots,m$, denotes the set of relations. Therefore, (p_i, p_j) denotes the interactions between manager p_i and p_j.

The management network and the operation network are inter-embeded. The interactions between the two networks can be further formulated as follows:

The situation, one type of manager has influence on some operating elements, and this can be denoted as:

$$M(p_i) = \{m_j | m_j \in M, \eta(p_i, m_j) = 1\}$$

Where, $M(p_i)$ denotes the set of operating elements affected by one type of manager p_i; $\eta(p_i, m_j) = 1$ denotes the influence that one type of manager p_i has on the operating element m_j, $j = 1,2,\cdots,n$. Therefore, n denotes the number of operating elements.

The situation where one operating element is influenced by some managers can be denoted as:

$$P(m_i) = \{p_j | p_j \in P, \lambda(m_i, p_j) = 1\}$$

Where, $P(m_i)$ denotes the set of managers who have an influence on the operating element m_i; $\lambda(m_i, p_j) = 1$ denotes that m_j is influenced by manager p_j, $j = 1,2,\cdots,n$. Where, n denotes the number of managers.

The above formulas depict the static relations. As the networks are dynamic and interact with the help of information transmission, there is a "flow", which is an important concept in the CAS theory. Transport system can be seen as a system composed of the operation-management dual-network (Figure1).

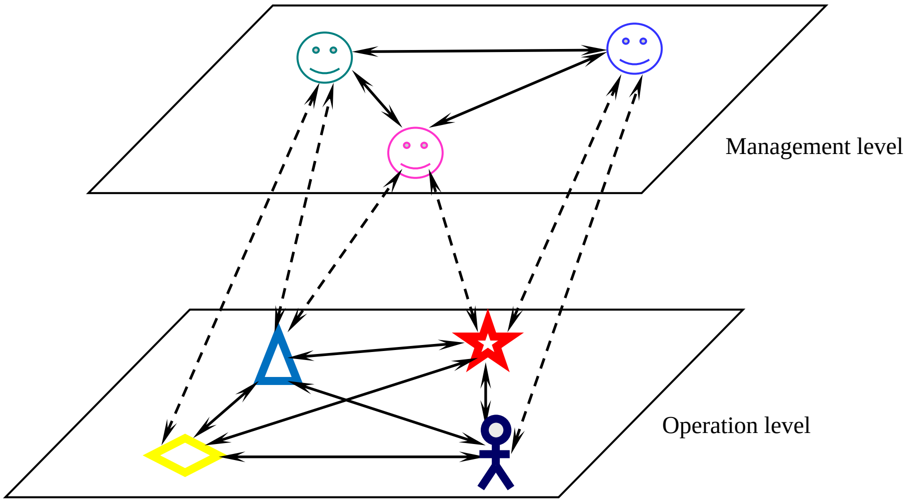

Figure 1: Abstracted dual-network structure

3. Collective Behaviour in the Operation Network Level

A direct impression about the impact of extreme weather events on the transport system might be a major traffic accident and a paralyzed traffic system. In fact, there are various ways that extreme weather events may impact on the transport system. Since the human is the most active element in transport system, extreme weather events will affect the traveller's cognition and behaviour, inducing accidents, resulting in extensive panic, and this might push the transport system into a chaotic state, and even lead to social unrest.

Collective behaviour might arise when transport condition gets worse under extreme weather events, and travellers are not informed about the current situation and what will happen next. Cognitive and psychological knowledge can help in analysing this phenomenon. The uncertainty of extreme weather may induce travellers' strain because travellers do not know about the likely duration of the event, the exact situation with respect to the event, whether the situation is controllable, and what might happen.

In this situation where there is a rare extreme weather event and an information shortage, the behaviour of a traveller is unavoidably influenced by others. Most individuals usually consider others' behaviour as being a conceivable choice to follow, rather than taking their own decision based on rational thinking. This phenomenon has universality, as social psychology studies have shown that such behaviour will become public information sources when the objective reality is blurred (Kelley et al., 1965; Quarantelli, 1957). Individuals often consider mass action as being valid, as other information and viable options are absent during the emergency situation. The most influential research to support this view is a set of articles published in Nature (Low, 2000; Helbing et al., 2000). Helbing et al. (2000) summarized some common characteristics about collective behaviour under emergency conditions, that is, "(1) People move or try to move considerably faster than normal. (2) Individuals start pushing, and interactions among people become physical in nature. (3) Moving and, in particular, passing of a bottleneck becomes uncoordinated. (4) At exits, arching and clogging are observed. (5) Jams build up. (6) The physical interactions in the jammed crowd can bend steel barriers or push down brick walls. (7) Escape is further slowed by fallen or injured people acting as 'obstacles'. (8) People show a tendency towards mass behaviour, that is, to do what other people do (9) Alternative exits are often overlooked or not efficiently used in escape situations."

The cascading dynamics of collective behaviour can be modelled by referring to the theory about herd behaviour (Lux, 1995). A traveller, who obtains incomplete information, tends to follow others' behaviours under emerging circumstances. The dynamics can be analysed by mathematical model (Miao et al., 2011):

Let $2N$ denotes the total number of travellers. Let n_- denote the number of travellers who are panicky and are inclined to follow irrational behaviour and n_+ denote the number of travellers who are calm and unlikely to act in an abrupt manner. $n_+ + n_- = 2N$. Let $n = 0.5\left(n_+ - n_-\right)$ and $x = n / N$, $x \in [-1, 1]$. If x is equal to zero, it means that the number of the panicky is equal to the number of the calm. If $x < 0$, the panicky will be the majority. If $x > 0$, the calm will be the majority. If $x = -1$, all travellers are panicky. If $x = 1$, all travellers are calm.

No matter whether the panicky travellers or the calm travellers become the overwhelming majority, the remainder will follow the majority. Let P_{+-} denote the transfer probability of travellers from the calm to the panicky and P_{-+} denote transfer probability of travellers from the panicky to the calm. The distribution of x or n will determine transfer probability, that is,

$$P_{+-} = P_{+-}(x) = P_{+-}(n / N) \tag{1}$$

$$P_{-+} = P_{-+}(x) = P_{-+}(n / N) \tag{2}$$

The above formulas show that one person will be influenced by others in the same manner. To simplify this problem, assume that the perception of a traveller may change only once. The panicky may transform to the calm based on anticipation and vice versa. Further, assume that everyone has the same probability of change. Then, $P_{+-}n_-$ denotes the number of travellers that have transferred from panicky to calm, and $P_{-+}n_+$ denotes the number of travellers that have transferred from calm to panicky. The transfer ratio can be denoted as

$$dn_+ \big/ dt = P_{+-}\, n_- - P_{-+}\, n_+ \tag{3}$$

$$dn_- \big/ dt = P_{-+}\, n_+ - P_{+-}\, n_- \tag{4}$$

Since $n = 0.5\left(n_+ - n_-\right)$ and $x = n / N$, then

$$\frac{dx}{dt} = \frac{0.5d(n_+ - n_-)}{Ndt} = \frac{1}{2N}\frac{dn_+}{dt} - \frac{1}{2N}(\mathrm{P_{+-}n_- - P_{-+}n_+ - P_{-+}n_+ + P_{+-}n_-}) \tag{5}$$

That is,

$$\frac{dx}{dt} = \frac{1}{N}(P_{+-}n_- - P_{-+}n_+) \tag{6}$$

Since $n_+ + n_- = 2N$ and $n_+ - n_- = 2n$, $n_+ = N + n$ and $n_- = N - n$

$$\begin{aligned} \frac{dx}{dt} &= \frac{1}{N}(P_{+-}n_- - P_{-+}n_+) \\ &= \frac{1}{N}(P_{+-}(N - n) - P_{-+}(N + n)) = (1 - x)P_{+-}(x) - (1 + x)P_{-+}(x) \end{aligned} \tag{7}$$

Since $P_{+-} > 0$ and $P_{-+} > 0$

Let $dP_{+-} \big/ P_{+-} = adx$ and $dP_{-+} \big/ P_{-+} = -adx$

Then,

$$P_{+-}(x) = ve^{ax}, \quad P_{-+}(x) = ve^{-ax} \tag{8}$$

Where, $\alpha \geq 0$ and v denotes the speed of change.

Then, the dynamics of the collective behaviour is depicted as

$$\begin{aligned} \frac{dx}{dt} &= (1 - x)ve^{ax} - (1 + x)ve^{-ax} \\ &= 2v[sinh(ax) - xcosh(ax)] = 2vcosh(ax)[tanh(ax) - x] \end{aligned} \tag{9}$$

Banerjee (1992) and Bikhchandani et al. (1992) brought forward the concept of information cascade. An informational cascade occurs when it is optimal for an individual, having observed the actions of those ahead of him, to follow the behaviour of the preceding individual, without considering his own information (Bikhchandani et al., 1992). This argument can explain the forming, frangibility and randomness of collective behaviour.

By referring to the basic ideas from Bikhchandani et al., the influence of emergent collective travel behaviour under extreme weather is analysed. Suppose every person has two kinds of behaviour, either rational or irrational, denoted respectively as *A* and *B*, and each has a probability of 0.5. Let *L* and *H* denote the private information. If *V*=*A*, individual is more likely to possess the information *H*; if *V*=*B*, individual is more likely to possess the information *L*. That is,

$$P(X = H \mid V = A) = p$$

(1 0)

$$P(X = H \mid V = B) = 1 - p \qquad (11)$$

Where, $0.5 < p < 1$

Similarly,

$$P(X = L \mid V = B) = p \qquad (12)$$

$$P(X = L \mid V = A) = 1 - p \qquad (13)$$

In addition to private information, each person can observe other individuals' behaviours before his decision-making.

The first person makes decision as per his own private information. Based on Bayesian formula, if he has private information *L*, he will choose behaviour *B*. This is because

$$P(V = B|L) = \frac{P(L|V = B) \times P(V = B)}{P(L|V = B) \times P(V = B) + P(L|V = A) \times P(V = A)} = \frac{p \times 0.5}{p \times 0.5 + (1 - p)} > 0.5 \quad (14)$$

The second person makes decision as per his own private information and the behaviour of the first person. If his private information is *L* and he observed the first person had chosen *B*, he will naturally choose *B*. If his private information is *H*, this situation is equivalent of decision-making under contradictory information, and the possibility that he will choose *A* or *B* is the same.

The third person makes decision as per composite consideration of his own private information and the behaviour of the previous two persons. If he observed both of them have chosen *B*, he will believe that their private information is *L*. Based on Bayesian formula, even if the third person has private information *H*, he will still choose *B*. This is because $P(V = A > 0.5)$ and information cascade of the *B* will emerge. It can be proved that the occurrence probability is $(1 - p + p^2)$. So, if $|N_A - N_B| \geq 2$, an information cascade may emerge and this will lead to collective behaviour. Under extreme weather, travellers tend to appreciate the more negative information, and this will increase the possibility of panicky collective behaviour. Therefore, on one hand, extreme weather will debase the connectivity and capacity of transport system; on the other hand, the collective behaviour triggered by panicky emotion and information shortage will easily lead to people's turbulence, which will in turn make the transport condition even worse. It is necessary to control collective behaviour to avoid greater losses than might occur through this “herd” behaviour. It is vital that public information is provided in a timely manner. Once the proper information is understood by travellers, the improper collective behaviour will get corrected.

The role of information provision is to guide rational behaviour. Travellers may encounter a lot of uncertainty from congested roads and from breakdowns. Failure to timely obtain accurate and timely information may induce an incident and this may in turn lead to large scale social unrest.

4. Activity in the Management Network Level

Under the risks of extreme weather events, the transport management department should send early warning information about the coming extreme weather, make quick response to accidents as they occur, and release relevant information to travellers. Effective assessment on the situation and swift response to accidents are critical in reducing the secondary effects and losses in the face of uncertainty under extreme weather conditions. Information collection is a necessary precondition for assessment and decision making. It is important to possess the following information: (1) Basic information, including time, location, road type, weather condition and traffic flow information, etc. (2) Event information, including the damage of infrastructures, casualties, condition about stranded vehicles and passengers, etc. (3) Resource information, including relief supplies, evacuation spots, technical equipment, etc. The acquisition of the above information needs to make full use of traffic detection devices, geographic information system and other transport management equipment. In addition, close collaboration with other sectors is important in information acquisition and release.

Situation analysis is the next important step. Based on the information obtained, it is imperative to make a quick analysis of the situation with the assistance of intelligent transportation equipment about the following: (1) Road network capacity, as this can be considered as a reference point to start a certain pre-arranged emergency plan. (2) Traffic congestion state, as this determines whether to provide relief and response. (3) Relief requirements, as this involves the information that will be released, the measures taken and the instruments used.

Situation prediction is a further important step. The risk evolution under extreme weather events is a random and uncertain process. With the expansion and transmission of the impacts of some accidents, swift prediction about what will happen next and what actions should be prioritised are critical. It is important to foresee the following aspects: (1) Potential danger to people, as this will directly affect the subsequent rescue and evacuation arrangements. (2) Potential damage to society, as this will influence further resource allocation and warning release.

In brief, the activity in the management network level is to match the requirements in the operation network level. But such a matching process is affected by various complex factors, such as the reliability of information source, speed of response, uncertainty of environmental change, etc. Therefore, the matching process has strong levels of uncertainty, and this is reflected in two aspects: the first is that the matching process is a fuzzy process that may not be accurately measured; the second is that the matching process will give rise to some random incidents that may be difficult to be foreseen. So it is better to consider the matching character from fuzziness and randomness view.

The theory about fuzzy cognitive matching (Atanassov, 1986) might provide a way to understand the essence of activities in the management network level and provide a means to describe the internal relationships between the dual networks under extreme weather events.

Let U denote a given universe, and let G denote a fuzzy cognitive subset in the universe U, that is,

$$G = \{\langle x, \mu_G(x), \gamma_G(x)\rangle \mid x \in U\} \tag{15}$$

Where, $\mu_G(x): U \to [0,\ 1]$ denotes membership function of G, $\gamma_G(x): U \to [0,\ 1]$ denotes non-membership function of G.

For any $x \in U$ that belongs to G, there is

$$0 \le \mu_G(x) + \gamma_G(x) \le 1 \tag{16}$$

If U is a continuum, then

$$G =_x \int \langle \mu_G(x), \gamma_G(x)\rangle / x, \qquad x \in U \tag{17}$$

If U is discrete, that is, $U = \{x_1, x_2, \cdots, x_n\}$, then

$$G = \sum_{i=1}^{n} \langle \mu_G(x), \gamma_G(x)\rangle / x_i, \qquad x_i \in U, \qquad i = 1, 2, \cdots, n \tag{18}$$

For any fuzzy cognitive subset of U, $\pi_G(x) = 1 - \mu_G(x) - \gamma_G(x)$ denotes the cognitive index of x to G and is a kind of estimation about the degree of uncertainty of x to G.

For fuzzy cognitive matching, the expected precondition to adopt a series of emergency arrangements is denoted as G, and the actual phenomenon is denoted as G'. Since G' cannot totally comply with G, an easy way to determine whether to adopt a series of emergency arrangements can be based on the comparison between G' and G. If the similarity is greater than a cognitive nearness λ, then transport managers can decided to start these emergency arrangements.

Cognitive nearness λ expresses a kind of fuzzy similarity between two situations. If let X and Y denote fuzzy sets corresponding to two situations respectively, the cognitive nearness $\lambda(X, Y)$ can be defined as

$$N(X, Y) = \frac{1}{2}\left[X \bullet Y + (1 - X \otimes Y)\right] \tag{19}$$

Where,

$$X \bullet Y = \frac{1}{2}\left\{\bigvee_U \left[\mu_X(x) \wedge \mu_Y(x)\right] + \bigvee_U \left[(1 - \gamma_X(x)) \wedge (1 - \gamma_Y(x))\right]\right\} \tag{20}$$

$$X \otimes Y = \frac{1}{2}\left\{\underset{U}{\wedge}\left[\mu_X(x) \vee \mu_Y(x)\right] + \underset{U}{\wedge}\left[\left(1-\gamma_X(x)\right) \vee \left(1-\gamma_Y(x)\right)\right]\right\} \tag{21}$$

Therefore, $\vee$ denotes take the maximum; $\wedge$ denotes take the minimum; $X \bullet Y$ denotes inner product; $X \otimes Y$ denotes outer product.

When nearness is utilised to express matching degree, greater value of nearness implies better matching.

5. Reflections from the Snow Event in South China in Early 2008

5.1 Basic description about the weather event

Between January 10 and February 2, 2008, there were four episodes of severe and persistent snow, low-temperature and freezing weather in the Yangtze River basin, in the South China and South-West China regions (Shi et al., 2010). It had seldom snowed in South China, so the heavy snow surprised many people, and there was no experience about how to respond to this rare event. The snow closed highways, as well as stranding millions of passengers. As reported by Xinhua News Agency on 27th January 2008, there were "more than 40,000 passengers in at least 5,000 broken-down vehicles on expressways between Guizhou province and neighbouring Guangxi Zhuang Autonomous Region; the delays of at least 136 trains in Hunan Province, a result of power failure, stranded almost 150,000 passengers at Guangzhou Railway Station on Saturday night" (Xinhua News Agency, 2008). By the end of January 2008, the number of stranded passengers in Guangzhou Railway Station has exceeded 1,000,000. However, the public were not told about the expected weather conditions in advance, and travel information was only limited in its relevance and quality. As a result, more passengers streamed into railway stations and they were trapped there. The slow response of local government caused public resentment and social unrest. As the complaints increased, emotions were raised, and there were disturbances in some stations. The state in these stations became difficult to control. China’s premier Wen Jiabao had to visited several railway stations to placate the stranded passengers. This sequence of the event illustrates the causal chain effects resulting from the extreme weather, causing subsequent collective behaviour, and it resulted in the increased risk of disturbance. This event demonstrates the interconnectedness between the sectors and the important role that transport plays in maintaining social harmony.

Figure 2 Map of China: Locations of provinces, autonomous regions and municipalities

5.2 Defects in the transport sector

Since the snow weather event is predicable and the intermittent snow lasted for almost a month, the first reflection on this event is why relevant officials failed to make effective preparations and a swift response to the heavy snow.

Many officials in South China believe snow events always happen in the northern regions and so they do not need to consider that matter themselves. “Warm winter" gossip had become popular in recent years, as it seems that winter is really not cold any more. Therefore, there is a prominent oversight on dealing with the potential problem of snow defence.

Starting in 2004, the total pre-arranged emergency plans in China had amounted to 24,293 items as of March 15, 2006 (Shi et al., 2007), but unfortunately, the vast number of pre-arranged emergency plans did not achieve desired results in the snow event response. The transport sector did not receive any relevant emergency training prior to the event and it did not establish effective advance emergency management systems.

The transport sector did not make special analysis, evaluation and judgement on the information from the weather forecasting sector. The land and the air transport sectors continued to sell tickets to passengers even when the heavy snow was already beginning to fall, and this resulted in passengers being stranded in stations. More frustrating was the fact that the central government had issued a warning notice to local officials, but these individuals failed to forward this message to those in the subordinate areas, as a matter of urgency. Full use was not made of the early warning time to try to control danger, and this resulted in the “golden time” being lost.

The severely affected southern provinces almost all demonstrated an acute shortage of snow clearing equipment. One typical example was that a highway in Jiangxi province possessed only one snow removal vehicle, and such a severe shortage of equipment led to traffic jams in this area that lasted for three days.

5.3 Defects in the interactions between other sectors

People's power in emergency response process has not been fully mobilised. Public participation can improve the efficiency in coping with extreme weather events, as this can involve the vast, extensive and quick response characteristics of civic society. If this potential can be fully activated, the ability of the transport sector to respond effectively would be considerably enhanced. Although China's emergency response planning clearly states the need to increase public participation, the real situation is far from satisfactory. There is an obvious gap between officials and citizens in terms of their ability to communicate and cooperate with each other. For example, some local governments have issued several notices to urge citizen to participate in the snow and ice cleaning, but few people are actively involved in this process.

In facing large-scale extreme weather events, it is unwise for the transport sector to act alone. It is better to cooperate with other related sectors so that the full range of actions can be taken in the emergency response process. However, handicaps in the coordination and communication with other sectors were prominent in the snow event. For example, the railway sector wished to resume the rail operations as soon as possible, and they publicised information that trains would restart in a few days. However, the local government in the affected area wished to comfort the stranded passengers, and they released contrary information to instruct the passengers to stay at the station and to celebrate the Spring Festival. The conflicting information made the stranded passengers, who have already become restless and strained with rising concerns resulting from the prolonged stay at the station, become even more annoyed, and this resulted in civil disobedience.

As highlighted earlier in this paper, information distribution plays a vital role in the interaction between the operation network and management network. Information availability and release are important issues that cannot be overlooked. Different departments may release different views on the same event, and so effective and coordinated mechanisms are needed for joint information distribution.

6. Discussion

Extreme weather events may not only impact on the physical components of transport system, but it may also induce social and psychological strain. Therefore, transport management under extreme weather risks should pay attention to not only physical aspects but also psychological and behaviour aspects of the situation. Preparedness and response to extreme weather events need a mass of information and resource, both of which require extensive collaboration between the different sectors. An active transport sector would anticipate the risks and send early warning messages to the operation network. Active anticipatory action can reduce the economic and life loss. A preferable system for transport management under extreme weather risks would be to: (1) distinguish the risks from potential extreme weather events and inform the operation network; (2) capture important information from the operation level and make swift response after extensive collaboration. In contrast, a passive transport management system waits for accidents to happen and then to make a limited response.

The snow event in South China revealed a range of incompetent transport managers, a lack of risk awareness, and an ignorance of the importance of communication and collaboration with other sectors. These factors resulted in crucial delays in organising and carrying out the emergency response.

When an event happens, many leaders from national to provincial and municipal levels can brave the wind and snow to go the frontline to visit and comfort the affected people, regardless of their personal safety. The more fundamental reaction is that the response was given the maximum attention, but anticipation and prevention was not given any real priority. The officials' achievements in crisis management process have been focused on the immediate reaction rather than being prepared in advance of such an event taking place, and this approach was condoned by their superiors. Although the central government has restated the message that the main emphasis of emergency management should be transferred from response to anticipatory management, the performance appraisal for officials has been focused on the response-based system. There is an obvious mismatch between the political slogans and the actual appraisal standards. If this situation does not change, similar problems in emergency management will persist and will recur in a similar fashion when the next serious weather event occurs. Therefore, effective incentive mechanisms must be implemented so that institutional and cultural change within the key organisations takes place.

The snow event also highlighted the importance of effective information provision in guiding travellers' psychology and behavioural responses. Uncertainty needs to be reduced through information provision to help travellers improve their self-adjustment capability, and this is an important topic for intelligent transportation system research. For example, information dissemination channels are commonly used with radio, television, internet and other public media (Khattak and DePalma, 1997). Television and internet can be used before a trip to help plan for specific external factors, such as extreme weather events, but they may not be so suitable for long travel considering the real-time requirements on information. Radio can release real-time information to travellers, but its effectiveness is constrained, as its usefulness needs to be made very specific in terms of locality, timeliness and relevance, as it is difficult to release important information for very specific conditions, for different locations, and for directing individual traveller behaviour.

Dynamic traffic information systems are better placed in this respect as information can be sent through mobile communication networks to personal mobile phones. When an accident arises on a certain road, relevant messages can be sent to the travellers, and alternative routes can be suggested to them. To ensure the accuracy and authority, local government needs to be involved in the construction and management of a dynamic information release system that covers wireless communication technology, transport geographic information system, database technology, and other devices. These need to be combined in a systematic way to reduce the loss caused by extreme weather events, and to direct daily traffic and enhance efficiency.

7. Conclusions

Extreme weather events are difficult for the transport sector to cope with, as it is often the transport system itself that is disrupted. But that same transport system is needed to provide the means by which emergency workers and supplies can get to the affected area. Anticipation and early warning, together with sufficient preparedness and swift response are all critical components in providing the means to reduce the impacts of extreme weather events. However, all these elements require close collaboration between the various sectors, each of which might be affiliated to different regions or different administrative organisations. Such social-techno system exhibits complexity in the dual-network. The operation network may present collective behaviour and induce new challenges for transport management. The effectiveness of emergency response lies in the matching of the activity in the management network with the requirements of operation network. Information transmission plays a critical role in such matching process. Evidence from the case study on the snow event in South China in early 2008 partly supports the theoretical formulation given in this paper, but other aspects need further research. These include the types and forms of information to be provided, clear leadership and coordination between the different agencies involved in responding to events, more consideration being given to anticipatory as well as responsive actions, and further exploration as to the means by which the public can be better engaged in playing an active role in event response.

Acknowledgements

The first author acknowledges the support from the Humanities and Social Sciences Fund of the Chinese Ministry of Education (09YJC630049), the Fundamental Research Funds for the Central Universities (HIT.NSRIF.2010082), the Research Fund for the Doctoral Program of Higher Education (20112302120037), the National Natural Science Foundation of China (71101036, 61074133), the Natural Science Foundation of Heilongjiang Province (G201014), and the Humanities and Social Science Guidance Programme of Education Department of Heilongjiang Province (11554097).

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