Building Resilience into Freight Transportation Systems

Actions for State Departments of Transportation

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The management of transportation systems for resilience has received significant attention in recent years. Resilience planning concerns the actions of an organization that reduce the consequences of a disruption to the system the organization manages. Little exploration has been made into the connections between resilience planning and the actions of a state department of transportation (DOT) that contribute to resilience of a freight transportation system. Conclusions are presented from collaborative research between the Washington State DOT Freight Systems Division (WSDOT FSD) and researchers at the University of Washington. Activities of the WSDOT FSD that contribute to resilience are identified, and one such activity undertaken by WSDOT to improve communication with system users is described. This and other activities can be undertaken by other DOTs that want to improve the resilience of their freight transportation systems at relatively low cost.

Businesses that have experienced external shocks and unforeseen transportation disruptions in recent years have paid significant attention to improving their organizations' resilience. Resilience has gained interest not only within the area of supply chain management but also within organizational theory, city planning, and transportation system management. Disaster research, ecology, social psychology, and computer science and engineering are other fields in which resilience has been studied for some time. The emergence of resilience thinking in an increasing number of fields coincides with the evolution and recognition of increasingly complex systems that structure the world. Advancements in information technology, data management techniques, computing methods, and communications have contributed to an increasingly interconnected, intricate webbing of relationships. The freight transportation system (FTS) is one such complex system. The use of resilience as a guiding framework for action emphasizes a holistic approach to FTS management and problem solving, necessary for addressing the complexities of the FTS.

Ta et al. outline a general definition of resilience for the FTS (*1*) that highlights six features of resilience that characterize organizations with potential for resilience: redundancy, autonomy of components, collaboration, efficiency, adaptability, and interdependence.

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They also define the FTS as consisting of three major dimensions across which they apply the definition of resilience: the managing organization, the users, and the physical infrastructure. Their work shows that resilience of the FTS is inextricably linked to resilience of each of the system's component dimensions. The result is an integrated definition of resilience that captures the multiactor, multiagency, and multidimensional features of the FTS.

The research presented in this paper focuses on the managing organization dimension and the role state departments of transportation (DOTs) play in supporting FTS resilience. Some organizational characteristics of the DOT that support resilience are presented along with specific actions a DOT can take as managers of FTS facilities and operations. The definitions of resilience for FTS are shown in Table 1.

The three dimensions of the FTS provide the structure for organizing DOT actions into three areas: organizational processes (for the managing organization), information dissemination (to benefit users), and modeling and infrastructure improvements. This paper focuses on the actions a DOT can take to enhance resilience of the FTS at each of the three dimensions of the FTS. The authors draw on the discussion of highly reliable organizations and collective mindfulness by Weick et al. (*3*) to inform the discussion of the organizational resilience of DOTs and to examine how a DOT contributes to infrastructure resilience and enterprise resilience.

FOCUS ON DISRUPTIVE EVENTS

Travel time reliability is a common indicator of transportation system performance, most notably because transportation decisions (e.g., route choice or time of travel) and transportation costs are affected by time spent on the roadway. Disruptions on the transportation system increase travel time, compromise user confidence in the reliability of the system, increase costs, reduce FTS reliability, and challenge economic vitality. The federal government's attention has centered on these types of events largely because of two recent national disasters: the events of September 11, 2001, and Hurricane Katrina. Most public planning for transportation system resilience in the United States has been for unanticipated catastrophic events such as disruptions from terrorist attacks or major natural disasters (*4*). The establishment of research facilities such as the National Center for Risk and Economic Analysis of Terrorism Events reflects the prominence of the issues.

Terrorist attacks that target major components of transportation infrastructure and earthquakes and other extreme natural disasters are higher-impact events that deserve attention; however, consideration of another set of disruptions that plague transportation systems—more-routine disruptions that are often lighter in impact—is also

TABLE 1   Definitions of Resilience for Freight Transportation System

Concept	Definition
Managing organization resilience	"Capacity to meet priorities and achieve goals in a timely and efficient manner in order to contain losses" (2).
Enterprise resilience	Capacity of an enterprise to move goods in a timely and efficient manner in the face of infrastructure disruptions.
Infrastructure resilience	Capacity of the network to move goods in the face of infrastructure disruptions.
FTS resilience	Capacity for the FTS to absorb shocks or reduce the consequences of disruptions. FTS resilience can be deconstructed along its component dimensions: the managing organization, the infrastructure and enterprises, the system's users.

important. Routine disruptions are not necessarily predictable disruptions, but they have a higher frequency of occurrence. These types of disruptions characterize common challenges for DOTs, including constrained highway capacity because of major accidents, fallen objects, avalanche and snow hazards, or seasonal flooding. This paper focuses on more-routine disruptive events because of their significant impact on freight travel and the costs they represent to businesses and the state. In a metropolitan region, routine events are not expected to happen each day, but they have the potential to happen each day and are not surprising when they occur.

Figure 1 is a generic vulnerability matrix that depicts a framework to relate higher-impact disruptions with lighter-impact disruptions (5). The matrix consists of four quadrants. Each quadrant represents a different type of vulnerability characterized by the degree of impact (consequence) and frequency of occurrence (disruption probability) (5). Events that fall into Quadrants I and III describe two types of events that plague the FTS. Quadrant III classifies the more-routine disruptions (high disruption probability–light consequence), and Quadrant I classifies major disruptions (severe consequence–low disruption probability). The development of strategies to respond to routine disruptions has the added benefit of contributing to an improved ability for the DOT to respond to more-rare, higher-impact disruptions (3). Through the effective management of recurring FTS disruptions, a DOT cultivates the characteristics and processes for a responsive, reliable, and resilient FTS. In Wildavsky's words, resilience is the "improvement in overall capability, i.e., a generalized capacity to investigate, to learn, and to act, without knowing in advance what one will be called to act upon, [which] is a vital protection against unexpected hazards" (6). For example, Pitera identifies the resilience strategies of corporations, FTS users (7). She finds that corporations prone to experience disruptions in their daily oper-

ations will tend to use more-effective resilience strategies. Their everyday experience prepares them for handling higher-impact disruptive events. Relating the experience of corporations to the DOT, Pitera suggests that a flexible culture in the DOT, improved communication with corporations, and better information exchange between the DOT and FTS users are vital to support enterprises' pursuit of resilience (7). Hence, the greatest yields in building resilience should focus on the routine management and oversight of the FTS and mechanisms for information exchange.

To increase the resilience of the physical infrastructure, the DOT can build new infrastructure to create network redundancy; however, these are particularly costly improvements, which often come with negative land use implications. Before undertaking physical improvements, a DOT could ensure these investments occur at the most-needed parts of the infrastructure. This can be accomplished through the use of modeling tools that capture the dynamics of the FTS. Ideally, these tools would be able to identify the economic value of elements of the infrastructure, for example, measuring the value of a roadway segment not simply by the number of vehicles it serves but by the economic value of these movements to the region. However, improvements in data quality and modeling methodology are needed before these tools will be readily available. Ongoing research activities are supporting these goals.

While pursuing rational investment decisions through modeling to better understand freight demands, a DOT can improve FTS resilience by encouraging users of the system to be more resilient. If system users have plans for responding to transportation disruptions, disruptions can be less problematic. This can be accomplished through outreach and education of enterprises and effective communication mechanisms to provide enterprises with real-time and predictive information about the state of the system.
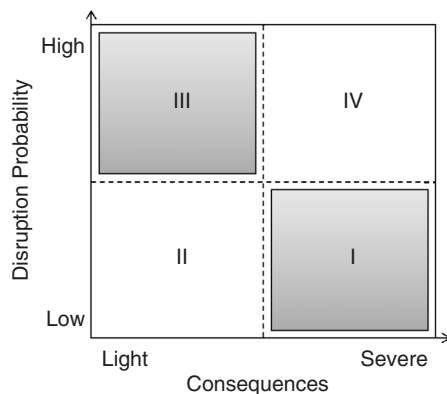
IMPROVING ORGANIZATIONAL RESILIENCE

Improving resilience within DOTs requires cultural change in the organization. Literature on positive organizational change, specifically work by Weick et al. (3), can provide insight into the necessary cultural shifts and how these changes could improve organizational resilience. The work of Weick et al. elaborates on collective mindfulness as a distinctive quality of highly reliable organizations, noting applications of mindfulness in the literature on team cognition, "team mind," and crewmember interactions for ship navigation. The concept of mindfulness was originally applied at the level of individuals, and Weick et al. extrapolate it to groups, suggesting five cognitive processes of mindfulness that yield reliability, and a low variance in performance, for organizations:

- Dedication to continuous improvement,
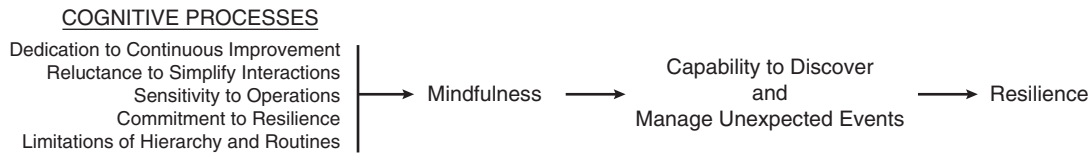- Reluctance to simplify interpretations,

FIGURE 1   Generic vulnerability matrix.

<u>COGNITIVE PROCESSES</u>
Dedication to Continuous Improvement
Reluctance to Simplify Interactions
Sensitivity to Operations
Commitment to Resilience
Limitations of Hierarchy and Routines

$\longrightarrow$ Mindfulness $\longrightarrow$ Capability to Discover and Manage Unexpected Events $\longrightarrow$ Resilience

FIGURE 2 Mindfulness framework for resilience.

- Sensitivity to operations,
- Commitment to resilience, and
- Limitations to hierarchy and routines.

The five cognitive processes of collective mindfulness induce "a rich awareness of discriminatory detail and a capacity for action" that supports an organization's "capability to discover and manage unexpected events" (*3*). The present paper applies the collective mindfulness framework of Weick et al. to DOTs and suggests that it lead not strictly to reliability but to resilience. Weick et al. use reliability to mean low variance in performance and predictability (*3*). Resilience, however, is about not predictability but actions and reactions to unwanted and unanticipated events or disruptions to a system. Figure 2 is adapted from Weick et al. to inform the presented framework and links collective mindfulness with FTS resilience (*3*). Collective mindfulness leads to the ability to discover and manage unexpected events, which is also referred to as situational awareness.

Dedication to Continuous Improvement

Dedication to continuous improvement means an organization is tuned to see the whats, hows, and whys of what went wrong. Additionally, the organization recognizes the near misses, or situations in which there was almost a failure. This increases the number of data points for learning. The ability to see a near miss to recognize possible dangers, disruptions, or devastations supports collective mindfulness or situational awareness (Figure 3). A dedication to continuous improvement also protects against the dangers that arise with a preoccupation with success—confidence, excessive trust in procedures, and fantasy (*8*). Overconfidence in the organization's ability from a preoccupation with success blurs the organization's ability to recognize the triggers of system failure.

Reluctance to Simplify Interpretations

Organizations that are reluctant to simplify operations appreciate the complexity of the transportation system and are determined to collect information, learn, and discover intricacies in transportation system operations. These organizations cross check claims and information sources and greet reports and information with constructive
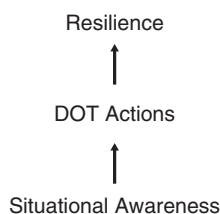
Resilience

↑

DOT Actions

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Situational Awareness

FIGURE 3 Conceptual representation.

skepticism (*3*). The organizations support the ability to simultaneously believe and doubt experience. Skepticism takes the form of diverse checks-and-balances mechanisms across committees and meetings; formalized organization renewal, review, and rejection processes; and frequent reviews and employee rotations, training, and retrainings (*3*). Individuals within the organizations also recognize that simplifications are based on necessary assumptions made about a complex system and remain critical to those assumptions.

Sensitivity to Operations

Sensitivity to operations implies that individuals within an organization will see the big picture and will understand the need to collaborate across areas within an organization (*3*). The ability to see the need to collaborate is a first step. Individuals within an organization must also be trained and fluent in methods of cross-group collaboration. Sensitivity to operations not only supports a keen perception of disruptions but also facilitates shorter response times for disseminating information within the DOT and consequently to FTS users.

Commitment to Resilience

An organization committed to resilience is devoted to identifying and employing actions that support the organization's ability to learn from disruptions, communicate across parts of the organization, and make decisions that prioritize resilience (*6*). This requires changing the current decision-making process, as resilience-improvement priorities will be added to the list of action items. Organizations committed to resilience do not wait for disruptions to arise before acting; rather they act more quickly by preparing for and learning from all disruptions. Thus, the organizations are better able to cope with surprises and to bounce back from future disruptions.

Limitations of Hierarchy and Routines

Finally, management with resilience in mind recognizes the dangers of a rigid hierarchy. "An orderly hierarchy can amplify errors [and in some organizations] . . . It is the very reliability [of predictability and routine] . . . that makes it possible for small errors to spread, accumulate, interact, and trigger serious consequences" that limit the ability of an organization to share solutions from one area of the organization to another (*3*). Hence, it is preferred that "hierarchical rank is subordinated to expertise and experience," where migration within an organization's employee structures "increases the likelihood that new capabilities will be matched with new problems" (*3*). For example, those responsible for triggering the flow of information from within the Washington State DOT (WSDOT) to freight system users are part of an institutional structure that enables them to start the flow of information whether they are members of the

TABLE 2   Six Features of Resilience in Freight Transportation System

Concept	Definition
Redundancy	Availability of more than one resource to provide an overlapping system function.
Autonomous components	Parts of a system able to operate independently.
Collaboration	Engagement of stakeholders and users in the FTS to promote interaction, share ideas, build trust, and establish routes of communication.
Efficiency	Optimization of input against output.
Adaptability	System flexibility and a capacity for learning from experience.
Interdependence	Connectedness of components of a system or the dimensions of a system, including the network of relationships across components of a system, across dimensions of a system, and between components and dimensions.

highway maintenance crew, regional maintenance supervisors or administrators, Emergency Operations Center freight desk managers, the communications group, or division managers. Freight Systems Division (FSD) staff and a core section of the statewide communications team have been trained to operate the WSDOT freight notification system.

FEATURES OF RESILIENCE

Recall the six features of resilience outlined by Ta et al. (*1*): redundancy, adaptability, interdependence, autonomy of components, collaboration, and efficiency. Table 2 provides a summary.

The remainder of this paper outlines high-value, low-cost actions a DOT can take to develop FTS resilience. A DOT's actions take the information gathered through situational awareness and act on it to increase FTS resilience. To address the connection between situational awareness and resilience, specific actions drawn from the experiences and activities of the WSDOT FSD are presented.

WHAT A STATE DOT CAN DO: WSDOT EXAMPLES

Recall that a DOT's actions can support resilience at each of the three dimensions of the FTS: managing organization, infrastructure, and enterprises (users). The actions can be grouped into three areas consistent with these dimensions:

1. Organizational processes that improve DOT resilience,
2. Information dissemination that improves enterprise resilience (Figure 3), and
3. Modeling and informed infrastructure capacity management that improve infrastructure resilience.

Figure 4 depicts the relationships between resilience, situational awareness, the DOT, and the three areas of actions that affect FTS resilience. This section of the paper examines some of the activities WSDOT has undertaken to increase the resilience of the FTS in Washington State.

Organizational Processes Moving Toward Organizational Resilience

WSDOT demonstrated a commitment to freight issues through the creation of the FSD. Since then, WSDOT has increased its emphasis on the needs of the freight community. In 2007, the FSD partnered with the Massachusetts Institute of Technology (MIT) Center for

Transportation and Logistics to interview more than 50 major shippers, carriers, and public-sector emergency planning team members in the Pacific Northwest to understand their needs and meet those needs in a state freight resilience plan. WSDOT made a commitment to protect Washington State's economy against the threat of transportation disruptions and provide better-quality service to freight system customers. The executives and division leaders supported many of the organizational processes that promote resilience. WSDOT was one of the first state DOTs to develop a customer-focused plan for freight transportation and today offers a model for other states to use in state FTS resilience planning (*4*). Through its freight resilience planning efforts, WSDOT developed a better understanding of the public sector's resilience capabilities and the needs of freight-dependent industry sectors. From the interviews and focus groups, WSDOT discovered that predictive information about highway conditions is the most valuable information it can offer to FTS users who need it to make effective routing decisions.

To develop greater internal organizational resilience, WSDOT made staff resources available to coordinate the FSD, the emergency management group, communicators, and the Traffic and Maintenance Division's work on freight resiliency. This work is part of a larger, ongoing effort sponsored by executive leadership to integrate truck freight services across all WSDOT functions. Specific results of the freight resiliency initiative include creating the first freight desk to troubleshoot truck-related issues within the WSDOT Emergency
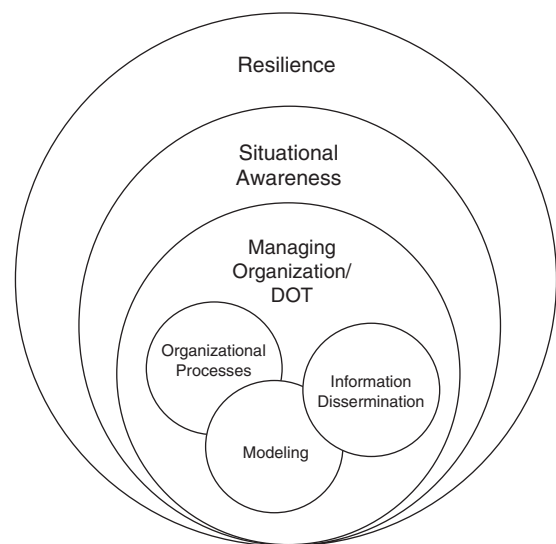
FIGURE 4   Conceptual diagram for organizing resilience and factors.

Operations Center, training statewide communicators to know which type of disruptions significantly affected truck freight and how to use the Freight Notification System, and documenting the economic importance of truck freight shipments to Washington State and disseminating that information across all departments in the agency (9).

FSD developed the freight resiliency plan with MIT in 2007 and began to implement the recommended organizational and operational changes during the 2007–2008 storm season in Washington State. Two major freight highway closures within 2 months elevated resilience to the top of WSDOT's agenda. During the 2007–2008 storms, flooding closed a section of I-5, the primary north–south highway through Washington State and the West Coast states, for 4 days, and avalanche danger closed I-90, the major east–west freight corridor for almost 4 days.

Before these closures, no communication system was in place to allow WSDOT to push current and predictive truck freight roadway conditions to shippers and freight carriers. WSDOT also lacked mechanisms with which to gather truck-related information internally and analyze its value to its freight customers, who faced uncertainties about their ability to make timely deliver of goods. Freight shippers and trucking companies need predictive information to plan for staffing, equipment, and inventory demands. When will the DOT reopen the highway? When will the detour be available? When it opens will trucks be allowed to use it? Although many DOTs provide real-time passenger information, they typically do not provide high-value freight-specific information such as the location of safe and legal detours for trucks or the estimated time of freight route reopening.

Faced with the closure of the state's most important freight highway and detours that either added 550 mi to the trip or could not replace the corridor's capacity, WSDOT FSD pushed for the prioritization of emergency truck freight operations and pioneered the freight notification system during the I-5 closure.

The notification system now provides freight users with accurate predictive information about the FTS during disruptive events, whether emergency events or planned events such as road closures for construction and maintenance. Predictive information is information about upcoming highway closures or restrictions, even if the closure's parameters are uncertain.

Following the major road closures caused by the storms, in 2007 WSDOT began to implement steps outlined in the WSDOT–MIT Freight Resilience Plan and continues to advance the resilience framework. In lieu of a mandate or any funding incentives, the FSD works through internal and external relationships with shippers, carriers, and public agencies to improve resilience. WSDOT is working closely with the state's Emergency Management Division of the Washington Military Department, the National Guard, and the Washington State Patrol to set policies and procedures for use of freight detour routes when capacity is greatly reduced. WSDOT FSD is partnering with the University of Washington and Washington State University on several resilience projects, including building a state freight model that can predict multimodal freight route changes caused by disruptions. WSDOT is also involved with TRB freight resiliency research. Table 3 provides a qualitative summary of WSDOT's actions that contribute to organizational resilience broken down by an action's contributions to situational awareness, the ability of any element of an organization to have knowledge about the operations of another element of an organization.

Information Dissemination: Proactive Tactics for Improved Enterprise Resilience

WSDOT enhances FTS resilience by gathering and organizing information about highway roadway conditions and providing this information directly to trucking companies and shippers via WSDOT's freight notification system. Members of the freight community subscribe to the system to receive notifications of changes to freight roadway status. This service has been very well received by state and national trucking companies and shippers. It is one of the most successful yet low-cost and quickly implementable changes undertaken by WSDOT to improve FTS resilience (user dimension). Before the system was introduced, shippers and carriers searched WSDOT's website to find information about road closures and detours. The website is still a primary source of current road conditions for trucking companies, but traffic information on WSDOT's website is tailored to passenger vehicle travel. Through the freight notification system, WSDOT proactively pushes information to freight system users.

TABLE 3 WSDOT Actions Toward Organizational Resilience

Contribution to Collective Mindfulness	WSDOT Actions
Dedication to continuous improvement	Debriefs state and out-of-state shippers and trucking companies after each significant freight system disruption to improve the freight notification system and truck freight highway operations. Developed a new, more comprehensive methodology to quantify the economic impacts of the 2007–2008 freight corridor disruptions. Improved methodology and results published in 2008 (10).
Reluctance to simplify interpretations	Based the goals of the FTS resiliency plan on shippers' and freight carriers' goals and supply chain practices. Solicited input from the larger Washington state freight transportation planning community to determine statewide freight resiliency model needs, uses, outputs and integration opportunities. Pursues phased research to advance FTS resilience through working relationships with universities AASHTO and TRB's National Cooperative Freight Research Program. Insists on high data quality and full accounting of costs and economic benefits in risk analysis undertaken to justify freight resiliency investments.
Sensitivity of operations	Understands WSDOT's role in the larger planning community and reaches out and includes other public and private organizations involved in transportation operations and planning.
Commitment to resilience	Pursues integration of freight resilience improvements across WSDOT planning, design, operations, communications, and project construction functions.
Limitations to hierarchy and routines	Leadership elevated the importance of truck freight moves and their direct association with economic output. Allows internal divisions to devise solutions. Encourages input from all levels of the organization, across the hierarchy, regarding the FTS conditions.

By providing this service, WSDOT meets users' needs by giving them predictive information, which lets them anticipate changes to the system before they occur. WSDOT determined the unmet need for predictive information through interviews with shippers and carriers. The e-mail notifications are modeled after the U.S. Customs and Border Protection Agency's border-condition e-mail notification format and provide information about the event, its location, its cause, and the extent of the impact plus when to anticipate the next update. WSDOT's freight notices may also include information on safe, legal truck detours and available truck parking, all of which helps shippers and carriers in their planning and decision making. Improved communication supports enterprise resilience, as there is more accurate and timely information for carriers to make logistics decisions. Users more experienced with disruptions in their normal course of business tend to be more resilient enterprises and find benefit from predictive information (7). Furthermore, FTS performance can be improved through this strategy because carriers can anticipate problems and reroute or reschedule goods movement, reducing the impact of the event on their operations.

From WSDOT's experience, three elements are necessary for a successful freight notification system: (a) developing truck freight situational awareness within the DOT, (b) obtaining a robust electronic information distribution infrastructure, and (c) maintaining a large freight shipper and carrier database. Situational awareness is defined as the DOT's ability to gather accurate real-time and predictive information about statewide freight highway disruptions and determine which events significantly affect freight carriers and shippers and which do not. The distribution infrastructure should enable fast, robust, and low-cost electronic distribution through multiple channels: e-mail, text, and voice mail. Many commercial companies offer this service at a low cost. Finally, the DOT must maintain a comprehensive database of freight shippers and carriers and associations that serve them to ensure targeted outreach to the widest range of freight system users possible.

WSDOT's freight notification system began with very few resources; no funds were available, only existing FSD staff resources. To develop and deliver other valuable services to freight shippers and carriers, the FSD from its inception collected customer contact information in a disciplined way. Beginning in late 2003, FSD built targeted industry- and region-specific freight e-mail distribution lists in Windows Outlook on the director's desktop computer and used the lists to stay connected to customers through the development of the state freight plan.

During the I-5 closure in December 2007, FSD began to use the contact lists to push freight-related information to users. But the temporary system had glitches: some contacts in different regional lists overlapped and received the same message several times, no one else in the agency had access to the director's desktop, electronic spooling

slowed the system down, and a power failure in the WSDOT headquarters building would stop the system. Even with its faults, the early freight notification system was rated a very high-value service in the 2007 I-5 closure debriefing, and WSDOT continued to improve it. In July 2008, FSD moved the freight notification system off the director's personal computer to off-site servers and away from a simple Outlook list to a commercial customer list-management service that distributes e-mail and text messages. In 2009, FSD trained a core group of the statewide communication team to directly enter information into the freight notification system, increasing the speed of information transmission to users.

In 2009, FSD began to build a stronger truck freight situational awareness process within WSDOT. The WSDOT FSD negotiates goals and facilitates cross-functional working groups that include relevant division leaders and staff to implement the objectives.

Modeling and Informed Infrastructure Capacity Management: Improved Infrastructure Resilience

WSDOT recognizes the value of obtaining quality freight data and improving analytic methods and is developing a statewide freight model to understand the impact of transportation disruptions on Washington's industry sectors. Washington State is investing in the freight model to defensibly estimate the cost of disruptions to businesses and to be able to rationally plan and prioritize strategies to protect economic activity. A freight model informed with the right type of data—corridor-level commodity flow data, truck speeds and volumes—can identify the relationships between industries and infrastructure use, prioritize vulnerable supply chains, and assist in infrastructure project prioritization.

SUMMARY AND RECOMMENDATIONS FOR STATE DOTs

This paper examined the public sector's role in contributing to a resilient FTS and outlines actions that DOTs may take to support freight resilience. The research identified actions that may be undertaken by DOTs, some at very low cost, that have been proved to improve system resilience in Washington State (Table 4). WSDOT's activities are based on the WSDOT–MIT state resiliency plan. Although changing internal priorities and processes requires executive sponsorship and significant staff resources in large organizations like DOTs, the benefit is a more resilient economy. WSDOT's experience shows that a DOT may realize some benefits quickly at low cost. After WSDOT instituted the freight notification system, WSDOT received many unsolicited responses from carriers thank-

TABLE 4   Summary of Actions

FTS Resilience	FTS Dimension	Area of Action	Action	Example
Organizational resilience	DOT	Organizational processes	Develop situational awareness	Establish freight desk positions within different divisions of the DOT. Partner with the state's emergency management division. Engage in freight resilience planning.
Enterprise resilience	Users	Information dissemination	Improve external communication	Develop a freight notification system.
Infrastructure resilience	Infrastructure	Modeling	Understand system operations	Pursue FTS modeling.

ing them for their work. Freight-dependent industries and trucking companies value predictive and current road condition information, especially predictive information, because it allows them to make more informed routing decisions, saving them money and reducing negative effects on the state's economy.

WSDOT's commitment to resilience resulted in defining staff roles and responsibilities to address and respond to freight issues throughout the organization, thereby increasing the organization's internal effectiveness. The WSDOT FSD continues to develop tools for predicting routing changes and the economic impacts of disruptions to the state's freight system. Vulnerability of the FTS is not unique to Washington. Although the combination of frequent severe weather systems and limited road network redundancy exacerbates Washington's FTS vulnerability, each state has its own risks, and any DOT can improve its FTS performance by undertaking some of the recommended resilient actions.

REFERENCES

1. Ta, C., A. V. Goodchild, and K. Pitera. Structuring a Definition of Resilience for the Freight Transportation System. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2097,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 19–25.
2. Haddow, G. D., and J. Bullock. *Introduction to Emergency Management.* Butterworth-Heinemann, Stoneham, Mass., 2004.
3. Weick, K. E., K. M. Sutcliffe, and D. Obstfeld. Organizing for High Reliability: Processes of Collective Mindfulness. *Research in Organizational Behavior,* Vol. 21, 1999, pp. 81–124.
4. *Development of a Statewide Freight System Resiliency Plan: Final Research Report.* MIT Center for Transportation and Logistics, Massachusetts Institute of Technology, Cambridge, 2009.
5. Sheffi, Y. 2005. *The Resilient Enterprise Overcoming Vulnerability for Competitive Advantage.* MIT Press, Cambridge, Mass., 2005.
6. Wildavsky, A. B. *Searching for Safety.* Transaction Books, New Brunswick, N.J., 1989.
7. Pitera, K. A. *Interpreting Resiliency: An Examination of the Use of Resiliency Strategies Within the Supply Chain and Consequences for the Freight Transportation System.* M.S. thesis. Department of Civil and Environmental Engineering, University of Washington, Seattle, 2008.
8. Starbuck, W. H., and F. J. Milliken. Challenger: Fine-Tuning the Odds Until Something Breaks. *Journal of Management Studies,* Vol. 25, No. 4, 1988, pp. 319–340.
9. *WSDOT Strengthens Freight Systems Division Management Team.* http://www.wsdot.wa.gov/News/2007/11/26_freightappointments.htm. Accessed July 10, 2009.
10. http://www.wsdot.wa.gov/NR/rdonlyres/77F51020-4607-44D2-A4F2-B1866B183B25/0/WSDOT_I5_90ClosuresFinalReport.pdf.