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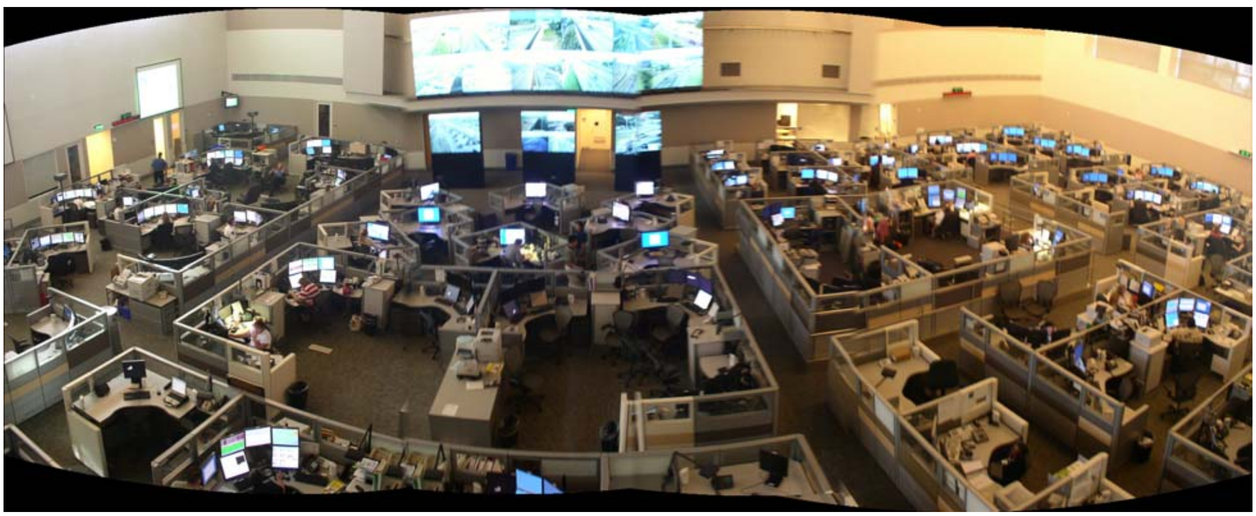
Final Report

Integration of Emergency and Weather Elements into Transportation Management Centers



February 2006

U.S. Department of Transportation
Federal Highway Administration

FOREWORD

This report offers a current view of the state of integration of weather and emergency information in Transportation Management Centers (TMC) across the country. The best practices described here demonstrate the high value of integration in ongoing management of local transportation systems. In combination with the lessons learned, they may be utilized by local and state officials to initiate, enhance and guide further integration projects.

Regina McElroy, Director
Office of Transportation Operations

Notice

Quality Assurance Statement

Technical Report Documentation Page

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16. Abstract

Integration as applied to transportation management and operations is a concept that reflects how Transportation Management Center (TMC) operators, agencies internal to the TMC, external agencies and support systems interact to improve transportation operations, safety, security and customer satisfaction. Integration is a catalyst and a tool for enhancing operational performance and is one of a variety of strategies available to, and used by, TMCs. This study is part of an ongoing Federal Highway Administration research effort that seeks to document transportation operations across the country and identify strategies that can enhance the operational effectiveness of transportation management systems in general and TMCs in particular. The TMC Integration study documents how weather and emergency information and systems are being integrated into transportation operations now and the potential for applying practical, effective concepts and methods of integration in the future. The study investigated the needs and opportunities for TMC integration of emergency and weather information and systems, and further explored the concepts, methods and potential for integration to benefit operations. Thirty-eight TMCs across the country that demonstrated current best practices in integration were interviewed and ten of those selected for site visits. A concept of integration and measures of integration attainment were developed and described. The state of the practice was reviewed, and challenges to integration identified along with strategies for addressing those challenges. Benefits of integration were presented, best practices described, and recommendations offered for how weather and emergency integration in TMCs could be initiated or enhanced. The practice of weather and emergency integration in TMCs is in its infancy, but the examples of best practices in selected TMCs across the country offer examples of the long-term value of an integrated approach to transportation operations that other TMCs can emulate. It is hoped that the lessons learned in this study can help inspire and guide widespread efforts to achieve the benefits of integration in more TMCs in the future.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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EXECUTIVE SUMMARY

Awareness of the effects of weather and emergency events on traffic operations, mobility and public safety has grown substantially in recent years. This study is part of an ongoing FHWA research effort that seeks to document transportation operations across the country and identify strategies that can enhance the operational effectiveness of transportation management systems in general and TMCs in particular. The TMC Integration study documents how weather and emergency information and systems are being integrated into transportation operations now and the potential for applying practical, effective concepts and methods of integration in the future. It is a thesis of this study that integration of weather and emergency systems and information into transportation operations, coupled with effective deployment of ITS, will improve performance and offer benefits in increased public mobility, safety and security.

Emergency integration is defined as follows:

> In a transportation management setting, emergency integration supports a TMC's capability to supply information and control transportation assets as needed to prepare for, respond to, and recover from an emergency. Emergency situations include damage to the transportation infrastructure, demand for transport of a population away from a threatened or dangerous location, and the need to provide access for emergency responders to a location.

Weather integration is defined as follows:

> Weather integration supports a TMC's ability to manage traffic, dispatch maintenance forces, and address weather-related emergencies. This is accomplished by providing TMC operators with accurate and timely weather and road condition information, effectively integrating weather and traffic information, and providing automated notifications and decision support.

The study investigated the needs and opportunities for TMC integration of emergency and weather elements and further explored the concepts, methods and potential for integration to benefit operations. Thirty-eight TMCs across the country were contacted (ten visited) that demonstrated current best practices in integration of weather and emergency information and systems. Before concepts and methods of emergency and weather integration could be developed, an integration framework was needed to help the study team understand the complex notion of integration. This framework was established and guided the study team to collect data and organize thoughts about this subject.

> *TMC integration reflects how TMC operators, agencies internal to the TMC, external agencies and support systems interact to improve transportation operations, safety and security. Integration is a catalyst and a tool for enhancing operational performance and is one of a variety of strategies available to, and used by, TMCs.*

The study documents an integration framework, the state of the practice, potential benefits, and challenges of emergency and weather integration. Additionally, several recommendations are made to further the development and deployment of emergency and weather integration in TMCs.

INTEGRATION FRAMEWORK ESTABLISHED

The study established an integration framework in terms of the *determinants of integration* and the *dimensions of integration*.

Any given concept of integration is shaped by the following four *determinants*:

1. The transportation context within the TMC's jurisdiction, including the configuration of roadways, various situational constraints on travel, and the mix of modal assets.
2. The TMC's exposure to weather or other potential disaster events, including the frequency, complexity and predictability of those events.
3. The institutional structure and organizational culture in the region, including the number and mix of agencies with transportation or emergency services functions, the types of plans and policies in place describing how to respond to events, and the presence of integration "champions" and institutional support for integration.
4. Access to resources that can facilitate and support integration, along with an understanding of the existing and available new systems and technologies, staff skills, and funding to support integrated applications.

The overall extent of integration at any TMC can be described in terms of the following five *dimensions*:

1. Operational Integration includes the ways in which data and information are shared and used by TMCs and connected agencies, organizations, and systems. The data are used to support traffic operations, integrated control of traffic systems, and shared decision-making with regard to TMC traffic functions. The remaining four dimensions support operational integration and are typically needed for successful operational integration.
2. Physical Integration represents how the agencies, organizations, and systems are physically linked or collocated for the purpose of sharing data or information in support of traffic operations.
3. Technical Integration is illustrated in how the data and information are exchanged and shared through physical linkages among people, systems and organizations, both within a TMC and between a TMC and other entities. This data and information exchange can be achieved through a range of means from verbal exchanges to automated electronic exchanges, and decision support systems that integrate available information to enhance operational efficiency and effectiveness.
4. Procedural Integration describes the development and use of policies, plans and procedures that support an integrated traffic operations in a TMC; the extent to which policies, plans and procedures are written down, made accessible to staff, reflect multi-agency interests and responsibilities, and are tested and reinforced with training and exercises; and, the coordination of policies, plans and procedures across integrated agencies and organizations.
5. Institutional Integration characterizes the level of commitment and partnership within and between participating organizations and agencies to achieve successful integration; leadership supporting the value of integration, and the willingness of partners to seek to collaborate to solve problems jointly; the clarity with which participant organizations' roles and responsibilities in support of integrated operations are spelled out and

understood; the vertical and horizontal collaboration within and between agencies and organizations in support of TMC traffic operations; and, agreements established among entities to support interaction and integration.

How a TMC operates in its unique environment, in response to the *determinants*, and how it integrates across the *dimensions*, defines the concept of integration for that TMC. This integration framework established the foundation for understanding how to characterize emergency and weather integration in TMCs and guided the efforts of the study team to describe current and future integration concepts and methods.

STATE OF THE PRACTICE DEFINED

The state of the practice in emergency and weather integration is illustrated by a set of core integration concepts and associated implementation methods. It was observed that significant differences exist in the implementation of integration concepts between emergency integration and weather integration. Emergency integration exhibited only one integration concept currently in practice with associated implementation methods, while weather integration demonstrated several concepts and implementation methods. The report documents the concepts and methods for emergency and weather integration. These concepts and methods include those currently being demonstrated and those potentially available to TMCs in the future.

A summary of the existing and future concepts for emergency and weather integration are:

Emergency Integration

Emergency integration concepts are divided into three categories of current concept extension, available concepts, and future research, as follows:

Current Concept Extension

- **Intercenter coordination** – collaboration and cooperation based on sharing information to assist management and experienced staff. Additional application would culminate in the operations centers of all organizations active in emergencies being tied together through a network of voice and data connectivity to coordinate their actions

Available Concepts

- **Operational coordination and training** – coordination of operational procedures and practices with other agencies active during emergencies under the National Incident Management System framework
- **Optimized emergency information integration** – implementation of rational and quantitative processes to direct continuous improvement in emergency integration

Future Research

- **Advanced tool support** – development and deployment of system and software tools to provide advice for actions that emergency managers can take to achieve transportation objectives in support of emergency management goals
- **Federal resources for rapid deployment** –a rapidly deployable set of resources that would provide any TMC the ability to field additional ITS components, communication

networks, or control center components when an emergency occurs that exceeds local resources

Weather Integration

All of the concepts below are demonstrated in some form in TMCs today:

- **Weather information coordination** – the management of weather information in a TMC and how it is, or may be, integrated.
- **Continuously available weather information** – a method, process or other structure in place at the TMC to bring weather information to the attention of those who can benefit from it. In the future these are expected to be automated, robust processes or structures.
- **Automated thresholds or escalation notification** – an automated notification system that triggers a weather situation alarm to notify operators of a developing and potentially dangerous condition.
- **Seamless integration of multiple sources and subsystems** – primarily a technical approach that assists transportation operators to perform their tasks by automating the manual collation of weather and traffic related information from multiple sources or in disparate forms.
- **TMC provides the operations center, administration and serves as a clearinghouse for weather information** – weather information such as RWIS, ALERT, FEWS, and 511 is in-house in the TMC and readily available at all times to aid with data management and interpretation.
- **Community awareness between the TMC and weather communities** – a form of institutional integration that brings together these two communities and enables the learning and enriched application of weather information use in the TMC.
- **Decision Support** – an evolving integration concept that will in time provide automated support to TMC operators based on a set of proven approaches to assist with transportation operation decision-making during, or prior to, weather events.

POTENTIAL BENEFITS IDENTIFIED

Benefits will vary depending on the conditions and level of integration at a TMC. Although a comprehensive analysis of the benefit-to-cost of emergency and weather integration has yet to be done in any objective, systematic manner, many observed and anticipated benefits are reflected in existing best practices at TMCs. The following potential benefits may be realized through the deployment of emergency and weather integration:

- Direct benefits dependent upon the quality and availability of advisory strategies, available transportation system control actions, and dispatch needs of integrated agencies.
- Improved emergency transportation operations through more efficient application of resources.
- Improved access to all regional information using compatible, standards-based systems over reliable communication systems.
- Ability to coordinate and pool resources to accomplish operations not currently possible.
- Improved clarity of roles and ability to communicate both in current operations and in future investments.

- Improved cost effectiveness through reduction in need to deploy duplicate resources.
- Quicker response to emergencies to clear roads, provide or move resources, and implement evacuation plans.
- More efficient evacuation activities through integration of traffic operations tools, strategies, and procedures.
- Improved public safety through reduced incidents resulting from more effective application of traffic management strategies that incorporate emergency and weather information.
- A common focal point for TMC-related agencies enhancing institutional, procedural, and operational integration.
- More timely and accurate information provided to the traveling public, thereby increasing customer safety and satisfaction.
- More efficient winter road maintenance operations by providing information, including Intelligent Transportation Systems (ITS) and Advanced Transportation Management Systems (ATMS) generated traffic and road condition information, to support treatment strategies.
- Better prepared TMC operators to address adverse weather on the transportation system in terms of appropriate staffing and implementation of traffic advisories and control strategies.

Many of these benefits were observed in TMCs by the study team. The TMCs that have implemented various emergency and weather integration concepts and methods (to achieve these potential benefits) did so by overcoming significant challenges.

CHALLENGES IDENTIFIED

The implementation of emergency and weather related integration comes with its own challenges. The approaches taken to implement these types of integration were specific to the needs of the region or state. Not surprisingly, the challenges were also specific to the needs of a particular TMC. This report addresses some of the challenges that might be faced by a TMC interested in emergency or weather integration. A list of these possible challenges includes:

Emergency Integration

- **Lack of strategic vision.** Decision-making by agencies with disparate goals in the absence of a strategic vision results in tactical progress and unintegrated operations without uniform direction toward improved emergency operations and the infrastructure necessary to accomplish those improvements
- **Access to traffic control strategies and devices.** State DOT TMCs have limited access to electronically controllable traffic control devices such as traffic signals and lane use signals that can be used to respond to emergencies, especially when the emergency initiates a spike in traffic demand.
- **Unique transportation context.** Each TMC exists in a unique institutional framework involving jurisdictional boundaries, governmental organization, private organizations, operational policies and local and state laws.
- **Lack of national-level TMC coordination.** TMCs across the country view themselves as fitting into a blend of three core functions: information clearinghouse, operations

center, and/or emergency manager. The unique approaches to operations and integration contained in each TMC are not easily shared with other TMCs that may be facing similar issues, and there is a lack of organizational structures to facilitate such exchanges.

- **Consensus decision-making.** In the setting of a public agency, the loss of ability to act independently can significantly delay actions that a single agency would initiate immediately, and unwillingness to compromise can prevent the possibility of cooperation.
- **Lack of reliability in legacy systems.** Existing systems are not always designed to be robust with the occurrence of component failures or emergency situations.
- **Data security and privacy requirements.** The legitimate data security concerns of law enforcement and homeland security organizations complicate the already difficult problems in data sharing.
- **Lack of benefits data and mature measures of effectiveness.** In competing for budget and institutional resources, emergency transportation operations integration suffers from a lack of perceived benefit.
- **Licensing restrictions on proprietary products.** Integration between centers using systems that are proprietary potentially faces licensing issues in sharing client software and access to custom protocols.
- **Differing legal bases for cooperating agencies.** When centers cooperate with centers representing other agencies, legal barriers and potential liabilities arise due to the roles and legislated protection given to each organization.
- **Lack of sustained investment in emergency transportation.** Once a region has either experienced an emergency with serious transportation impact or observed a nearby emergency, the planning and integration process takes on significant urgency.
- **Insufficient funding.** All centers identified available funding as a constraint. Most of the funding constraints limited staffing for either operational, management, or engineering activities.

Weather Integration

- **Lack of national-level TMC coordination.** The challenge regarding the lack of mechanisms and organizational structures to facilitate coordination and communication was discussed under emergency integration above.
- **Recognizing opportunities for weather integration and building support to address them.** In most TMCs weather integration is not a focus of the center, and many opportunities to enhance capabilities are not acted upon.
- **Lack of awareness of the use of weather information in traffic operations and integration opportunities.** Few TMCs are aware of how weather information may be used in traffic operations. The TMCs that successfully overcame this challenge did it by understanding how different weather conditions affected their transportation system and management approaches.
- **Access to traffic control strategies and devices.** State DOT TMCs have limited access to electronically controllable traffic control devices such as traffic signals and lane use signals that can be used to respond to weather events, especially when the weather event suggests adjustments to such control devices to facilitate traffic demand.

- **Reliance on non-robust systems and information sources.** Except in a few highly integrated TMCs, much of the weather information used by TMCs is non-transportation specific information generated for broad public consumption and is received over the Internet from the World-Wide Web or cable television.
- **Variations in the determinants of integration.** Various determinants of integration for a particular region or state including transportation context, exposure to events, institutional structure and climate, and access to resources have large variations from one jurisdiction to another which could drive the different solutions.
- **Limited national experience with TMC weather information integration.** There is very limited and disparate experience nationally to use as examples to illustrate the benefits of weather integration.
- **Understanding the benefits of weather integration versus the costs of implementation.** The cost of weather integration was expressed as a challenge by almost all the TMCs contacted. TMCs have found it difficult to show justification for the allocation of scarce funds for weather integration.
- **Need for the National ITS Architecture to better reflect the emerging use of surface transportation weather in transportation applications.** The National ITS Architecture (NITSA) is an important tool to facilitate and organize ITS integration activities in a TMC. Integration of weather information at a TMC goes beyond the present representation within the current version of the National ITS architecture where weather is identified as a terminator supporting the NITSA. To have the full benefit of weather information within the NITSA, the formation of additional market packages that more closely integrate weather information with operations and decision support are needed.

RECOMMENDATIONS MADE TO ENHANCE EMERGENCY INTEGRATION

Six recommendations are made to enhance emergency integration in TMCs. They are documented in detail in this report and summarized below.

1. **Extend the current concept of collaboration and coordination to comprehensive coverage of agency centers and information -** TMCs should expand information sharing to a network including operations centers of all organizations active during emergencies, including the return to normal operations.

2. **Improve coordination capabilities of traffic and emergency operation staffs -** TMCs should develop interagency operations procedures and participate in joint education and training covering response to incidents of all scopes under the National Incident Management System framework

3. **Develop quantitative measures of emergency integration and emergency operations -** To make rational decisions and discuss trade offs for use of limited resources, decision makers need quantitative terms for use in analyzing the benefits of emergency integration. MOEs should be developed that address effectiveness of integration, effectiveness of operations, and risk exposure for the emergency transportation need.

4. **Establish an optimal level of integration at each TMC and in each region -** TMCs should rationalize the process of establishing increased levels of integration.

5. **Develop advanced decision support tools for emergency transportation operations -** FHWA should sponsor research into advanced tools to assist emergency transportation managers in making strategic and tactical decisions.
6. **Develop emergency resources available for rapid deployment -** FHWA should sponsor research into development of assets available for rapid deployment when needed in a region experiencing an emergency situation.

RECOMMENDATIONS MADE TO ENHANCE WEATHER INTEGRATION

Nine recommendations are made to enhance weather integration in TMCs. They are documented in detail in this report and summarized below.

1. **Create an institutional culture within the TMC that is aware of weather information and how it can be used to improve operations -** TMCs should establish a weather operations advisory committee or designate an individual as the weather information coordinator.
2. **Provide awareness-building and training for TMC management regarding the benefits of targeted/tailored weather information in TMC operations -** It is recommended that outreach, education materials and training be provided to increase the awareness of targeted/tailored weather information sources, tools, and integration of best practices/techniques.
3. **Conduct a TMC weather information use self-assessment program and develop an integration plan -** TMCs should conduct a self-assessment to help identify the most effective integration solutions and guide their deployment.
4. **Develop a set of guidelines to enhance TMC integration of weather information -** A set of guidelines should be developed to provide a roadmap of potential integration concepts and methods that could be implemented by TMCs interested in weather information integration enhancements. These guidelines should address all five dimensions of integration (operational, physical, technical, procedural, and institutional).
5. **Improve communications between weather and transportation communities involved in traffic operations -** It is expected that improved communications between weather and transportation communities, specifically traffic operations, will result in increased awareness of roles, responsibilities, expectations and limitations of capabilities within each community.
6. **Investigate potential future concepts and methods -** Investigation of more appropriate concepts and efficient and effective methods to implement these concepts should be pursued as part of an on-going process to better utilize weather information within TMC operations.
7. **Develop a toolkit to assist in the integration of weather and traffic information sources -** Existing software and hardware tools available to support the integration of weather and traffic information should be identified and promoted for use in fostering improved integration activities.

8. **Foster a focused road weather research program supporting TMCs -** The future growth of weather integration and utilization within TMC operations will depend not only on the willingness of the TMC personnel to adopt the integration paradigm but also the presence of solutions to existing challenges involving weather conditions. The development of expanded research opportunities will foster a willingness of the research community to address these problems and to transfer the resulting technology to TMCs.
9. **Establish management strategies and rules of practice to support improved operations and enhanced weather integration –** Establish management strategies and rules of practice to provide a pathway to improved TMC operations. These become transferable standard operations actions that permit a measure of uniformity in operations across TMCs.

CONCLUSION

Transportation Management Centers are established across the country to integrate data, information and systems in support of day-to-day traffic (highway and transit) and emergency operations. Each part of the country presents a unique set of challenges to effective TMC integration based on climate, geography, politics, and transportation systems and resources. Depending on the concepts and methods of integration pursued by a TMC, the time and effort required will vary. The ability of TMCs to successfully compete for the limited available funds to support a more integrated approach to operations requires leadership, a supportive institutional environment, and the political will to invest in procedures to accomplish what are perceived to be unclear benefits and, in the case of emergencies, to address infrequent risks.

This study has examined the best examples of TMC integration and described the underlying concepts and methods of integration that are being employed to enhance transportation operations. The practice of weather and emergency integration in TMCs is in its infancy, but the best practices identified in selected TMCs across the country offer examples of the long-term value of an integrated approach to transportation operations that other TMCs can emulate. It is hoped that the lessons learned in this study can help inspire and guide widespread efforts to achieve the benefits of integration in more TMCs in the future.

1. INTRODUCTION

1.1 PROJECT BACKGROUND

The Office of Operations of the Federal Highway Administration (FHWA), U.S. Department of Transportation, is the sponsor of this Transportation Management Center (TMC) integration study. For more than a decade the FHWA has been encouraging the widespread deployment of Intelligent Transportation Systems (ITS) to increase transportation system efficiency in the face of growing demand (more vehicles traveling more miles) and severe constraints on supply (difficult and costly to build more road infrastructure). Awareness of the effects of weather and emergency events on traffic operations, mobility and public safety has grown substantially in recent years. The FHWA emphasizes that "uncoordinated deployment of independent systems that are not integrated and which cannot communicate with neighboring or complementary systems provide little if any benefit."[1] It is a premise of this study that integration of weather and emergency systems and information into transportation operations coupled with effective deployment of ITS will improve performance and offer benefits in increased public mobility, safety and security.

> *TMC integration reflects how TMC operators, agencies internal to the TMC, external agencies and support systems interact to improve transportation operations, safety and security. Integration is a catalyst and a tool for enhancing operational performance and is one of a variety of strategies available to, and used by, TMCs.*

This project is part of an ongoing FHWA research effort that seeks to document transportation operations across the country and identify strategies that can enhance the operational effectiveness of transportation management systems in general and TMCs in particular. Enhanced integration facilitates effective transportation operations, especially when transportation infrastructure is affected by weather or other natural or man-made events. Building on the prior research base, this project seeks to document the needs and opportunities for TMC integration of emergency and weather elements and further explore the concepts, methods and potential for integration to benefit operations. A Baseline Conditions Report has been prepared that documents screening interviews with 38 TMCs and site visits with 10 of those TMCs (see Appendix A[2]). The Baseline Conditions Report developed a concept and measures of integration and documented the integrated operations and best practices of 10 of the more advanced TMCs across the country.

> The TMC Integration study documents how weather and emergency information and systems are being integrated into transportation operations now and the potential for applying practical, effective concepts and methods of integration in the future.

This final report builds upon the baseline findings and looks to the future potential of integration in TMCs, while recognizing the uniqueness of local conditions, operating environments and transportation management experience. It explores how the concepts and methods of weather and emergency information integration can be advanced, how challenges to integration can be identified and overcome, and how TMCs can be guided to more effective transportation operations through integration regardless of their starting point.

A recent study by Science Applications International Corporation (SAIC) sponsored by the FHWA Office of Operations examined the concept of operations during emergencies and produced several reports.[3] The initial SAIC report identified the needs of transportation and emergency operations for information and tools that can enhance operations during natural and man-made disasters. Integration of information and decision support across participant agencies was identified as critical for improved performance. A companion report prepared by SAIC for the FHWA presented a vision for the next six years "for enhancing the capabilities of freeway transportation managers and freeway traffic management centers (TMCs) to support emergency operations in their communities (p. 4)."[4] This report distinguished emergency transportation operations from traffic incident management, pointing out that these emergency events will "have specific requirements for multi-discipline and multi-jurisdictional coordination that will not be addressed in a typical traffic incident management program (p. 5)." It presented a vision for improvement, through planning, policy development, institutional relationship-building, technical connectivity, and "renewed commitment to multi-organization cooperation (p. 7)."

The FHWA sponsored a similar study to develop a concept of operations for managing weather events.[5] This concept is grounded in three basic operational objectives: maintain and improve safety, maintain and improve mobility, and improve agency productivity. According to the study, to achieve these objectives with regard to operating under adverse weather conditions, a transportation agency gathers information and seeks to predict or anticipate potential impacts, and employs mitigation strategies either in anticipation or in response to impacts. The report concludes that, while weather-responsive traffic operations offers great value to managers, "this concept will be enhanced by [the] establishment of mechanisms for improved coordination within transportation agency divisions and between transportation agencies and other key response agencies…(p. 4-1)."

Two recent efforts are particularly relevant in support of increased integration of weather information into transportation operations. The first is a National Academy of Science study that provides recommendations for research to "provide a framework to engage the transportation and weather communities [to help them] capitalize on existing capabilities and take advantage of opportunities for advances (p. 2)."[6] The second is the *Clarus* initiative, discussed in a recent draft report that documents its concept of operations.[7] *Clarus* provides a network through which TMCs can access surface weather data and transportation conditions, and it provides for development of models and tools that can enhance a TMC's ability to forecast weather conditions and potential impacts on road conditions.

This report on TMC integration builds on prior research on the concept of operations in TMCs and the FHWA's efforts to enhance transportation safety and efficiency through closer collaboration between traffic operators, weather providers and emergency service providers.

1.2 INTEGRATION FRAMEWORK

The project baseline report shows that each TMC faces a different mix of circumstances and operational challenges, and a different set of needs for which better integration could be beneficial. Is more integration always better? This study demonstrates that the benefits from increased integration depend on how well integrated the TMC already is, their perceived need for further integration, and a set of conditions that help determine the value that integration can offer. The baseline study also made clear that one concept of integration does not fit all TMCs. A *concept* of integration describes *what* integration looks like in a particular TMC application; and the *methods* of integration describe *how* a particular concept of integration can be achieved. This final report presents current concepts and methods, based on observed best practices in some TMCs, and explores a vision of future concepts and methods of integration for weather and emergency elements. It seeks to clarify the circumstances under which a TMC can be expected to benefit from enhanced integration.

> A conceptual framework is helpful in explaining how an integration concept is shaped in a particular TMC, faced with real event challenges, drawing on available resources and institutional support.

A concept of integration reflects a blending of four key determinants that influence the "look and feel" of integration in any particular TMC. Figure 1 offers a conceptual framework for considering why a concept takes the form it does, as well as a set of strategies for achieving integration. Any given concept of integration is shaped by the following four determinants:

1. The <u>transportation context</u> within the TMC's jurisdiction, including the configuration of roadways, various situational constraints on travel, and the mix of modal assets.
2. The TMC's <u>exposure to weather or potential disaster events</u>, including the frequency, complexity and predictability of those events.
3. The <u>institutional structure and organizational culture</u> in the region, including the number and mix of agencies with a transportation or emergency services organization, the types of plans and policies in place describing how to respond to events, and the presence of integration "champions" and institutional support for integration.
4. <u>Access to resources</u> that can facilitate and support integration, along with an understanding of the existing and available new systems and technologies, staff skills, and funding to support integrated applications.

How these four determinants are experienced at a TMC shapes the structure and potential of integration (the concept of integration) in support of the operational functions and outcomes desired by the TMC. Integration supports the observed core functions of a TMC, such as traffic control, incident management, and dissemination of information to travelers, by facilitating better inter- and intra-agency decision-making and bringing accurate, relevant real-time data from a variety of sources inside and outside the TMC to address transportation management. Integration also has the potential to support advanced technologies and decision tools in advancing the operational effectiveness of TMCs in the future.

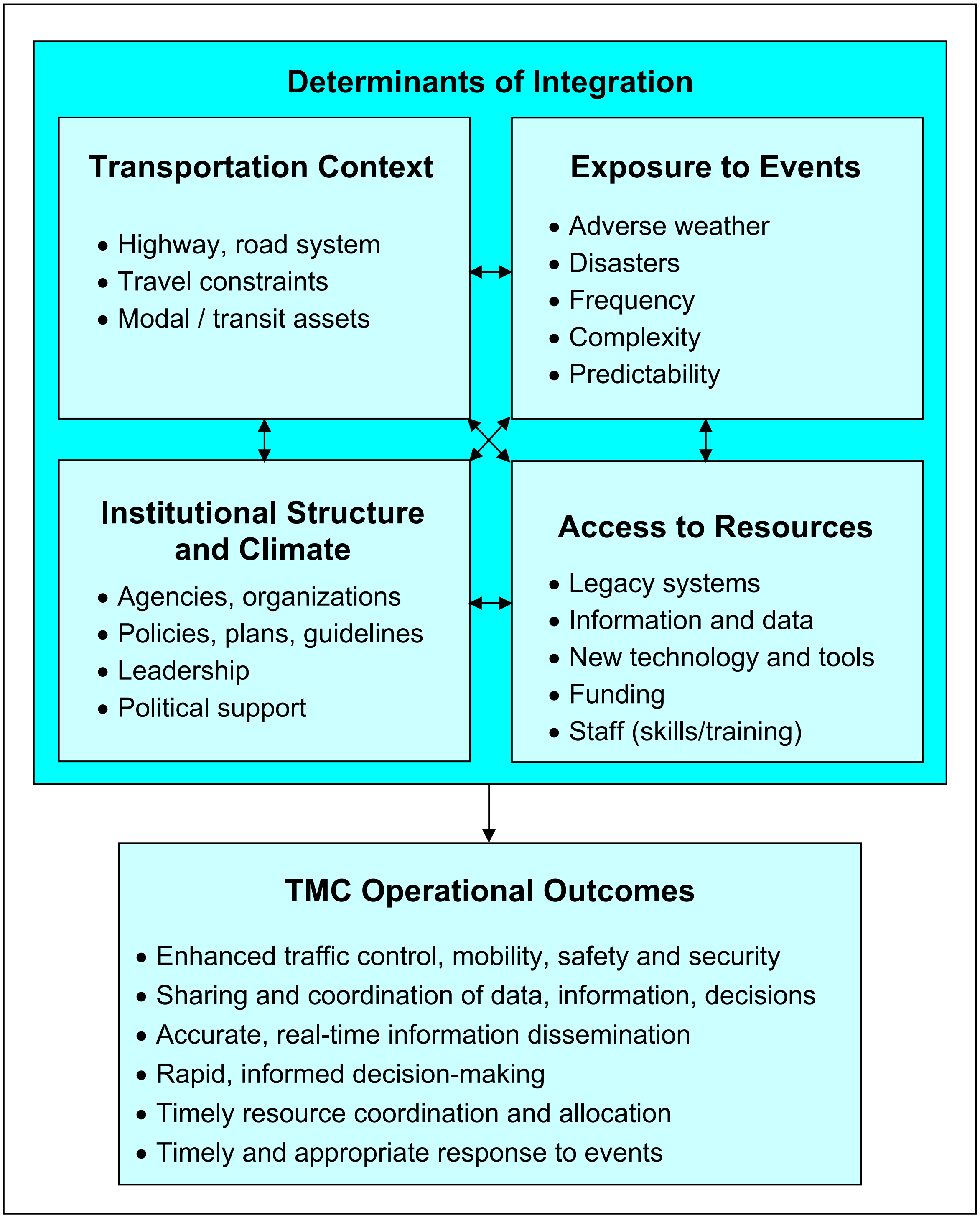

Figure 1. Conceptual Framework: Integration Determinants and Outcomes.

1.2.1 Purpose of Integration

Interviews with TMC operators across the country as part of the baseline data gathering for this project confirmed a shared understanding of the purpose of integration.

> *The purpose of weather and emergency integration is to achieve optimal performance of a TMC in managing the transportation system during weather and emergency events in support of their customers' needs.*

TMCs are very practical in seeking efficient and effective ways to better manage traffic and transit operations. The presence of weather-related events or regional emergencies increases the challenge and complexity of TMC operations, and underscores the practical benefits to be derived from coordinating with maintenance, law enforcement, incident management, fire and emergency management services, and hazardous materials experts. Integration represents a tool TMC operators can use to make better use of available data and expertise from linked agencies to support effective decision-making and action. A challenge in this project is to identify ways to communicate the need for integration to TMCs that currently exhibit a wide range of operational integration, from none to highly integrated. Appropriate concepts of integration will vary depending on the transportation context, nature of events faced by the TMC, and the operational needs of the TMC, as illustrated in the conceptual framework. Understanding where TMCs are on the dimensions of integration, as discussed in the next section, helps guide the identification of an appropriate integration concept and implementation strategy.

1.2.2 Dimensions of Integration

Integration can take many forms in support of operational performance, and it is helpful to look at the concept of integration in terms of its main component dimensions. These are illustrated in Figure 2. The baseline review of integration across numerous TMCs made it clear that successful operational performance can result from very different combinations and levels of integration across four major dimensions. A fully evolved TMC is itself an integration concept and method reflecting a high level of integration across each of the dimensions. TMCs exist to integrate technologies, agencies and information to improve the safety and efficiency of highway and transit systems. TMCs across the country exhibit a blend of three core functions: information clearing house, operations center and emergency manager. How a TMC operates in its unique environment, as determined by factors shown in Figure 1, and how it integrates across the dimensions shown in Figure 2 defines the concept of integration for that TMC. Most TMCs would agree that operations can always be improved, and most also agree that increased integration on these dimensions serves to enhance their operations.

The overall extent of integration at any TMC can be described in terms of the following five dimensions:

- **Operational Integration.** The ways in which data and information are shared and used by TMCs and connected agencies, organizations, and systems to support traffic operations, integrated control of traffic systems, and shared decision-making with regard to TMC traffic functions. The remaining four dimensions support operational integration.

- **Physical Integration.** The agencies, organizations, and systems physically linked or collocated for the purpose of sharing data or information in support of traffic operations.

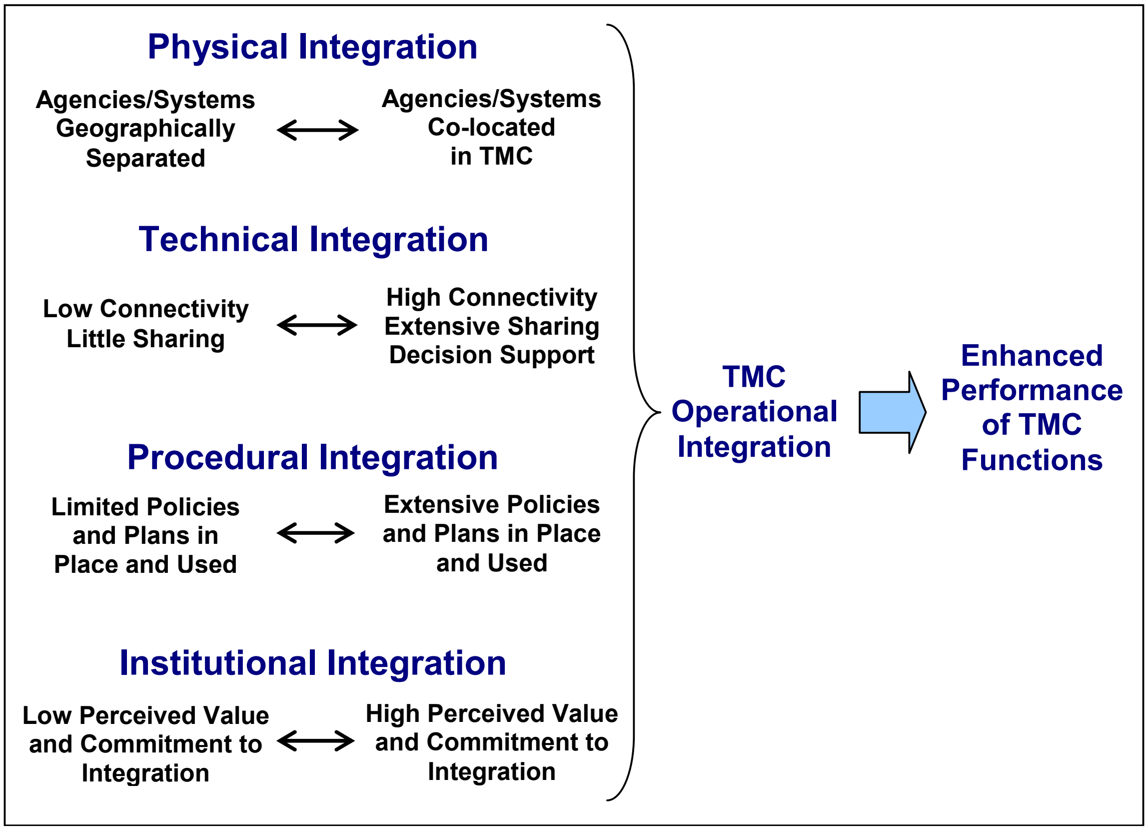

Figure 2. Component Effects of Integration Dimensions on TMC Functions.

- **Technical Integration.** The data and information communicated, exchanged and shared through physical linkages among people, systems and organizations, both within a TMC and between a TMC and other entities. This data and information exchange can be achieved through a range of means from verbal exchanges to automated electronic exchanges and decision support systems that integrate available information to enhance operational efficiency and effectiveness.
- **Procedural Integration.** The development and use of policies, plans and procedures that support an integrated traffic operations in a TMC; the extent to which policies, plans and procedures are written down, made accessible to staff, reflect multi-agency interests and responsibilities, and are tested and reinforced with training and exercises; and, the coordination of policies, plans and procedures across integrated agencies and organizations.
- **Institutional Integration.** The level of commitment and partnership within and between participating organizations and agencies to achieve successful integration; leadership supporting the value of integration, and the willingness of partners to seek to collaborate

to solve problems jointly; the clarity with which participant organizations' roles and responsibilities in support of integrated operations are spelled out and understood; the vertical and horizontal collaboration within and between agencies and organizations in support of TMC traffic operations; and, agreements established among entities to support interaction and integration.

1.3 STUDY APPROACH

The approach taken in this study has included the following steps to explore the concepts and methods of weather and emergency information integration:

- Reviewed prior research on TMC operations related to weather and emergency events.
- Conducted screening interviews with 38 TMCs across the country with the objective of identifying for site visits 10 TMCs that demonstrated current best practices in integration of weather and emergency information and systems. Diversity was sought on the determinants of integration shown in Figure 1.
- Conducted site visits with these 10 highly integrated TMCs and gathered data on their systems, organization, decision-making, and responses to weather and emergency events.
- Held a workshop with FHWA, representatives from a subset of the TMC sites that were visited, members of the project team, and representatives of selected agencies and organizations to review the baseline findings and explore a vision for future integration and how it can be achieved.
- Developed strategies for communicating the benefits of integration that are helpful to TMCs in meeting their operational and customer support needs.
- Developed concepts and methods for improved integration, some of which were observed at TMCs and identified as best practices and some proposed for future consideration.
- Identified future research needs in integration that could lead to more comprehensive guidelines.
- Prepared this final report that describes effective, practical, forward-looking concepts of integration; a range of methods for accomplishing integration; and challenges encountered and how they can be overcome.

1.4 REPORT CONTENTS

The remaining sections of this report include Emergency Integration (Chapter 2), Weather Integration (Chapter 3), and Conclusions (Chapter 4). Chapters 2 and 3 provide an in-depth review of current and potential future integration concepts and methods, integration challenges that TMCs may face, and recommendations for FHWA and/or TMC managers to consider as the country moves forward to enhance the level of emergency and weather integration.

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[1] Federal Highway Administration, Office of Operations. 2004. *Facilitating Intelligent Transportation Systems Deployment.* USDOT web site: http://www.ops.fhwa.dot.gov/

[2] The baseline document is attached for reference purposes. This final report presents and updates the concepts and

methods information contained in the Appendix.

[3] Federal Highway Administration, Office of Operations. 2004. *Concept of Operations for Emergency Transportation Operations.* Prepared by Science Applications International Corporation. (January 9).

[4] Federal Highway Administration, Office of Operations. 2004. *Vision 2010: Enhanced National Capabilities for Emergency Transportation Operations.* Prepared by Science Applications International Corporation. (January 9).

[5] Federal Highway Administration. 2003. *Weather-Responsive Traffic Management: Concept of Operations.* Draft report prepared by Cambridge Systematics, Inc. (January 10).

[6] National Research Council of the National Academies, Committee on Weather Research for Surface Transportation: The Roadway Environment. 2004. *Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services.* Washington, D.C.: The National Academies Press.

[7] Federal Highway Administration. 2005. *Clarus: Draft Concept of Operations.* Report prepared by Iteris, Inc. and Meridian Environmental Technology, Inc. February 18.

2. INTEGRATION FOR EMERGENCIES

2.1 OVERVIEW

In a transportation management setting, emergency integration supports a TMC's capability to supply information and control transportation assets as needed to prepare for, respond to, and recover from an emergency. In order to fully discharge their responsibilities in emergency situations, emergency management agencies require support in a variety of functions. The National Response Plan[8] designates transportation as Emergency Support Function #1. This designation recognizes the critical importance of transportation in an emergency situation. Emergency situations include damage to the transportation infrastructure, demand for transport of a population away from a threatened or dangerous location, and the need to provide access for emergency responders to a location. All of these situations may apply in a single event. In most instances transportation in an emergency setting is a derived demand, meaning that the demand for transportation is based on the need for a change in location of people and material. In fact, transportation for recreational purposes in emergencies is routinely discouraged and frequently prohibited by civil authorities.

> In a transportation management setting, emergency integration relates to the ability to supply information and control transportation assets to prepare for, respond to, and recover from an emergency.

In characterizing emergency integration, the study team drew a distinction between two different types of emergencies:

- Localized emergency. Typically localized emergencies impact the transportation system and a limited number of people or amount of property in a specific location. TMCs address these emergencies using resources under their control or resources with which they routinely interact. For example, a car fire that closes a single freeway lane is an emergency situation for the occupants of the car, but the impact is limited to the immediate vicinity of the fire and transportation staff members interact with fire, police, and possibly rescue squad staff members in a manner that is repeated on a nearly daily basis. The upper bound of such a localized emergency would be the closure of an interchange blocking two or more routes (all lanes) due to an emergency situation such as a hazardous materials incident.
- Disaster emergency. A disaster situation, usually involving activation of a regional EOC by the Office of Emergency Management (regional or state) involves extensive regional damage and threatened substantial loss of life. Regional governments address these situations by activation of a regional Emergency Operations Center (EOC) that houses representatives from many governmental agencies as well as non-governmental organizations. The EOC is operated under the coordination of an Office of Emergency Management or Emergency Management Agency (regional or state). Many of the TMCs included in this study have a command center or Transportation Emergency Operations Center (TEOC) to coordinate transportation responses separately from the regional EOC. The TEOC is dedicated to transportation issues and is located within the TMC or at a separate facility. The TEOCs are equipped with facilities beyond typical TMC capabilities and host DOT staff to handle widespread emergencies. Disasters would be

expected to have a greater impact than just a localized disruption of the transportation system.

While the focus of this study is on disaster-level emergencies, a majority of the experiences of TMCs and therefore the basis for integration at the working level relate to the management of localized emergencies.

For the purposes of this study, the study team developed a scale of integration for each dimension discussed in Section 1.2.2. Table 1 provides a description of levels zero to three for each dimension. In the physical dimension, the descriptions are different for localized emergencies and disaster situations. The descriptions are slightly revised from those used during the baseline analysis to fully reflect the most current thinking of the study team and to be consistent with the concepts and methods in Tables 5, 6, and 7. The 0 to 5 scale will build on this by adding two additional levels to provide for more advanced forms of integration and the evolution of potential future integration concepts and methods.

Table 1. Emergency Integration Measurement Scale: Dimensions and Levels.

<table>
<tr><th>Level</th><th colspan="2">Definition of Integration Level for Each Integration Dimension</th></tr>
<tr><td colspan="3">Operational</td></tr>
<tr><td>0</td><td colspan="2">No operational coordination between TMC and any other emergency agency</td></tr>
<tr><td>1</td><td colspan="2">Indirectly acquired information with time delay; limited knowledge of actions of some other agencies or impacts of decisions</td></tr>
<tr><td>2</td><td colspan="2">Directly acquired information with or without time delay; Substantial knowledge of actions of most other agencies or impacts of decisions; indirect request for device control.</td></tr>
<tr><td>3</td><td colspan="2">Full operational coordination among all emergency agencies and awareness of impacts of decisions.</td></tr>
<tr><td colspan="3">Physical</td></tr>
<tr><td>0</td><td><u>Localized Emergencies</u>
TMC and all emergency agencies are located separately</td><td><u>Disaster Situations</u>
TMC, TEOC, and all emergency agencies are located separately</td></tr>
<tr><td>1</td><td>Liaisons present for some emergency agencies in TMC</td><td>Liaison from TMC present at separate TEOC and/or one or more regional EOC(s)</td></tr>
<tr><td>2</td><td>Collocated operations with some emergency agencies</td><td>TMC/TEOC collocated with one of several EOCs</td></tr>
<tr><td>3</td><td>Collocated operation of all emergency agencies</td><td>TMC with TEOC capabilities collocated with single regional EOC</td></tr>
</table>

Table 1. Emergency Integration Measurement Scale: Dimensions and Levels (continued).

Level	Definition of Integration Level for Each Integration Dimension
Technical	
0	No data retrieved or transmitted
1	TMC systems exchange publicly available information with systems of other agencies
2	TMC systems exchange a subset of information with systems of other agencies
3	TMC systems exchange all relevant information with systems of other agencies and have capability for shared control and facility backup.
Procedural	
0	No documentation, written plans or policies in place or being used in support of integrated operations during emergencies. No joint multi-agency training or emergency exercises provided. No adherence to national standards
1	Informal, unwritten emergency coordination plans
2	Some agencies have written emergency coordination plans and some adherence to standards
3	All agencies have and use written emergency coordination policies and plans. Staff are offered multi-agency joint training and exercises in support of integrated operations under emergency conditions in compliance with national standards
Institutional	
0	No agency coordination. No active management support for building collaborative, integrated relations among a set of agencies or entities. No agreements are in place that encourage institutional integration in support of emergency operations.
1	General ideas of roles, responsibilities, and decision authority of agencies' emergency coordination; no agreements in place.
2	Formal agreements with some agencies and informal with others; occasional staff and management interaction.
3	Formal agreements with all agencies; frequent staff and management interaction. Management places a high value on integrated, collaborative working relationships and decision-making.

The subsequent subsections related to emergency integration present analysis of the study findings and offer recommendations for improvements in current integration concepts as well as concepts not currently in use that have potential to improve integration and thereby performance in emergency situations.

2.2 STATE OF THE PRACTICE

The study team examined some of the leading practitioners of emergency transportation operations. The systems and processes in use by the practitioners are the result of custom engineering work based on the vision of leaders in the context of their state or region. In conjunction with the custom engineering work, extensive institutional work was required to facilitate coordination of agency management and staff in the approval, funding, and joint use of the tools implemented.

2.2.1 Concepts and Methods

The implicit concept implemented by all current practices is one of intercenter coordination to allow operational control center and dispatch groups from multiple agencies to coordinate response to the greatest extent possible using information available from the cooperating agencies as well as outside sources such as contract weather services and the media. Managers, dispatchers, and operational staff with remote devices use a number of techniques to exchange information on the current situation and in some cases coordinate deployment of field resources using the expertise of their management and most experienced staff members. Although the concept is to coordinate control centers, in some cases the control centers are collocated in a combined facility.

A common characteristic among all sites studied is that the EOC needs situational awareness of both the demand on the transportation system and the available supply of transportation service (roadway infrastructure and vehicle fleet). This need can be satisfied by voice communication between a transportation manager and a liaison at the EOC, but is more adequately accomplished through a system connection between the TMC and the EOC with video and traffic surveillance data being transmitted to the EOC. To adequately satisfy the need for transmitting situational awareness, communication from the TMC to the EOC must be highly reliable and continuously active. A high bandwidth flow of electronic data is desirable.

The information flow from the EOC to the TMC consists primarily of decisions made by the EOC that either impact the operation of the TMC or must be implemented by assets controlled from the TMC. The needed communication can be performed by voice, with no significant advantage to system interconnection. The needed characteristic for the information flow channel from the EOC to the TMC is reliability, with increased availability and bandwidth having little advantage.

The most significant assets for emergency operations that are controlled by a TMC include Closed Circuit Television (CCTV) cameras, freeway service patrols, state maintenance fleets, variable message signs, highway advisory radio transmitters, 511 traveler information systems, and web sites. Traffic signals, which are the most common traffic control device and potentially the most beneficial, are controlled by local jurisdictions, which typically have limited access to the emergency operations resources. Media can be significant assets both for informing the public of valuable information collected by the TMC and for gaining information useful to the TMC.

TMCs participate in operational processes activated in emergency situations. Reversible lanes are frequently controlled from TMCs, with most reversible lanes found on HOV facilities, surface streets, bridges, and tunnels. Contraflow operations are more unusual than reversible lanes and rarely have related infrastructure that is controllable from the TMC, with implementation of contraflow operations requiring coordination with decision-makers outside of TMC staff and support from law enforcement. In both sites visited that have contraflow plans in place, the Governor makes the decision to initiate contraflow operations, with input from the upper management of state law enforcement, state emergency management, and the state DOT.

2.2.2 Current Practices

The centers interviewed for this study represent some of the leading centers in terms of integration and operations. Many of the procedures and systems in use were developed independently for the centers. The current practices display similarities based primarily on the common functions to be performed. The current practices also display a variety of approaches to solving common problems and performing common functions.

Each of the 10 TMCs that were site visited shared certain characteristics related to emergencies. These TMCs:

- were related to an EOC, TEOC, or both to support emergency operations beyond localized emergencies;
- supported one or more regional EOCs;
- could continue operations at some level in case of infrastructure outages including power and telephone; and,
- provided the facilities and capability for each agency (DOT as well as others with routine presence on the operations floor) to continue operations during an emergency without relocating their operational staff.

The TMCs also displayed significant differences in how they addressed emergencies. While each TMC was related to an emergency facility, the nature and extent of the physical integration of the TMC and EOC varied widely. These TMCs were:

- located in the same building;
- located on the same campus, with shared data and video networks;
- located remotely with private data networks; and,
- located remotely with data accessible via public infrastructure.

Table 2 describes the best practices, including locations where the practices were observed and a brief description of how the practices were implemented.

Table 2. Observed Best Practices for Emergency Integration.

Best Practice	Locations	Observed Implementation
Placement of TMC workstations in related EOC – Technical Integration	Houston TranStar	Location of regional EOC in the same building as the TMC allows data networks to be connected, giving EOC workstations full access to TMC data resources
	Austin CTECC	Location of regional EOC in the same building as the TMC allows data networks to be connected, giving EOC workstations full access to TMC data resources
	Georgia NaviGAtor	Location of the TMC on the same campus as the statewide EOC allows placement of a TMC workstation connected to the NaviGAtor system in Atlanta with full functionality
	Maryland CHART	Connection of the statewide emergency management center to the CHART system using ATM protocols on commercial communication infrastructure gives the CHART workstation at the EOC full functionality and acceptable video quality
Establishment of interagency agreements at management level – Institutional Integration	Houston TranStar	Formal agreements among local and state government agencies carrying signatures from high-ranking officials covering establishment, funding, management, and operations of the combined center
	Austin CTECC	Formal agreements among local and state government agencies carrying signatures from high-ranking officials covering establishment, funding, management, and operations of the combined center
	Orlando FDOT D5	A general memorandum of understanding establishes an organizational structure and documents commitment for information sharing and implementation coordination
Implementation of a data network on publicly-owned infrastructure and available only to regional cooperating agencies – Technical Integration	Orlando FDOT D5	Installed fiber owned by individual consortium members is interconnected to establish a region-wide Ethernet network private to the consortium used for sharing video, data, and remote server access.
	Salt Lake City	Installed fiber is interconnected with local partner agencies to establish a region-wide Ethernet network private to the agencies used for sharing video and data

Table 2. Observed Best Practices for Emergency Integration (continued).

Best Practice	Locations	Observed Implementation
Collocation of Operational Agencies – Physical Integration	Houston TranStar	Collocation of primary operations site of state DOT district operations, transit dispatch, and transit police along with representatives from regional police, traffic operations, and commercial traffic reporters allows pooling of resources and establishment of familiarity among staff members from all agencies.
	Austin CTECC	Collocation of primary operations site of state DOT district operations, city and county police, regional emergency medical service, and fire department with representatives from city traffic signal operations and transit dispatch allows pooling of resources and establishment of familiarity among staff members from all agencies
Collocation with Emergency Operations Center – Physical Integration	Houston TranStar	Collocation of operations site for several organizations in the facility housing multi-agency EOC brings benefits in availability of resources and familiarity of staffs to emergencies requiring an activation of the EOC.
	Austin CTECC	Collocation of operations site for regional agencies in the facility housing EOC and Office of Emergency Management headquarters benefits in availability of resources and familiarity of staffs to emergencies requiring an activation of the EOC
Restricted Access Website – Technical Integration	Pennsylvania Turnpike	Access from the TMC and other authorized organizations to a website operated by the Pennsylvania Emergency Management Agency allows for a two-way flow of highly accurate incident information with higher reliability to the website than publicly available websites provide.
Regular Interaction Among Agencies when responding to Localized Emergencies – Operational Integration	Pennsylvania Turnpike, Austin, Orlando, Houston, Salt Lake City, CalTrans D7, Maryland CHART	Many of the centers encourage staff interaction on both a task basis and a casual basis to foster working relationships among staff members. The most common interaction is between TMC staff and law enforcement, but also can include emergency medical, fire, transit, and hazardous materials agencies.

Relative to data exchange (technical integration), the range of connectivity between the TMC and EOC included:

- shared local area data and video networks;
- shared private wide area network using Ethernet technology and video encoding; and,
- commercial data access from publicly available providers such as Internet service providers and telephone service to analog modems.

Relative to directness of coordination with the EOC (a component of institutional integration), three models have been implemented:

- TMC communicates with a TEOC staffed with only DOT personnel, which in turn coordinates with one or more multi-agency EOC(s);
- TMC communicates with a single multi-agency EOC staffed with personnel from the DOT and a variety of other agencies from throughout the region; and,
- TMC communicates with several multi-agency EOCs staffed with personnel from the DOT and a variety of agencies from a single jurisdiction.

Relative to continuity of operations, all TMCs could continue operations at some level with loss of public infrastructure, including power, communication, and water services. The range of remaining capabilities included:

- ability to continue for several days with food, water, sleeping quarters, showers, power, and air filtration resources located at the TMC;
- backup power only with no other accommodations for extended staff operations;
- communication with a subset of field devices over a survivable data network; and,
- dependence on the public infrastructure for operation of devices outside of the facility.

By using best practices and existing resources, the state of the practice in TMC emergency integration can be significantly improved. In the judgment of the study team, five of the seven practices were highly relevant for both local emergencies and regional emergencies. Table 3 lists the identified best practices along with an assessment of their relevance to localized and regional emergencies.

Table 3. Local/Regional Relevance of Integration Best Practices.

Integration Practices	Relevance	
	Local Emergencies	Regional Emergencies
• Placement of TMC workstation in other centers	High	High
• Formal agreements at management level in support of collaboration	High	High
• Region-wide, private data network	High	High
• Collocation of operations from multiple agencies	High	High
• Collocation of TMC with EOC	Low	High
• Passworded EMA website access	Low	High
• Regular interaction among multiple agencies	High	High

The **placement of TMC workstations in other centers** allows management, dispatch, and operations to fully access TMC resources, even when the systems of the centers do not exchange data. Placing workstations in cooperating centers can be accomplished with less cost than modifying software to perform center-to-center data exchange, while retaining system security by using current-generation security approaches and TMC system accounts with limited privileges. The exchange of workstations is enabled by readily available communications technology such as dedicated WAN, ATM, or VPN access over the Internet. Placement of workstations in other centers also supports placement of TMC staff at those centers for exceptional circumstances, since the TMC staff have available the resources with which they have experience.

Formal interagency agreements represent a management commitment to establishing and continuously improving operational cooperation. The details of the agreements vary based on the factors discussed as part of the conceptual framework for integration. Topics covered by the agreements may include common interpretation of operational goals, operational policies, organizational roles, processes for review, and funding formulae. While many of the agreements allow agencies to unilaterally revoke the agreement, the trend in each location was for the agreements to expand in both the topics covered and the number of agencies participating.

The installation and sharing of a **private data network** enables exchange of information among centers, while leaving management of the bandwidth and access in the hands of representatives from the participating agencies. The current technology used in the shared data network is standards-based using Ethernet. This approach allows participating agencies to use commercial products and common networking practices to exchange video and traffic data as well as to use client software to access remote servers. Based on sites studied, once a backbone is justified and established, additional agencies willingly connect to the network, having to only pay for the marginal cost for the expansion while bringing additional data resources with them to the network.

The **collocation of operations from multiple agencies** leverages the resources of each to develop a center with more capabilities. Collocation requires a facility large enough to house both operations in a common area and management with separate office space. Sharing of infrastructure costs allows for installation of equipment with additional capabilities. Sharing of facility operations and maintenance functions reduces redundant staff requirements. The physical sharing of space increases the awareness of the actions of other agencies. The routine interaction of staff members builds working relationships.

The **collocation of the TMC with the EOC** entails the cooperation of a wide variety of agencies active during regional emergencies. Facilities are needed for providing coordination and communication. Similarly to collocation of routine operations, the collocation of a TMC with an EOC allows for the leveraging of resources. Especially important to the TMC are the resources required for EOC operation such as backup power, backup communications, and staff shelter. Sharing of information between the EOC and the TMC is also enabled, as is the establishment of working relationships that are important in emergency situations.

When agencies are not collocated, sharing of information is routinely a major issue. Many of the agencies provide information to the public using web pages. **Passworded accounts** help to overcome some of the reliability issues related to peaks in demand and accuracy of incoming information. A lead agency establishes a common site for sharing of relevant information. The participating agencies gain access not granted to the public, allowing them to have a more reliable connection than the general public. Typically, the participating agencies also have trained observers who are allowed to enter information that is of interest to partner agencies, thereby increasing the value of the information sharing to all agencies. To utilize readily available infrastructure, such sites use Internet communication techniques.

Best practices previously mentioned encourage **regular interaction among agencies**. The specific mention of routine interaction reiterates the value of establishing working relationships with agencies that are routinely involved in localized emergencies. While additional agencies are involved in regional emergencies, each agency involved in localized emergencies is still active during regional emergencies, and established relationships can be called on during the rapid activity of an emergency situation. Management encourages both task and casual interaction among staff. Task interaction includes routine operations as well as training events.

2.2.3 Challenges

Each center and staff member interviewed in the study could relate challenges that had to be addressed to establish the level of integration that has been realized. Some of the challenges encountered were faced by many of the TMCs given similarities in their functions and resources. Other challenges were unique to an individual TMC as dictated by the unique geographic, technical, political, and legal landscape each TMC faces. The following challenges observed during the study are offered in the hope that TMCs can address the challenges that they will face with less disruption to the implementation of improved integration and operations.

Lack of strategic vision. The typical development of the agencies involved in emergency transportation results in agencies making independent decisions that may or may not be supportive of interacting agencies. The agencies involved have disparate goals, structures, and resources. This type of decision-making results in tactical progress and unintegrated operations without direction toward a regional vision for improved emergency operations and the infrastructure necessary to accomplish those improvements. The centers that have accomplished extensive implementations and multi-agency and multi-jurisdictional integration have been lead by champions who forged such a regional vision. The presence of such a vision forms a basis for resolution of many challenges.

Access to traffic control devices. State DOT TMCs have limited access to traffic control devices that can be used to respond to emergencies, especially when the emergency initiates a spike in traffic demand. Most traffic signals are controlled by local jurisdictions that have limited access to the emergency operations resources. In some states, traffic control devices on state routes are controlled by state traffic signal organizations, but still are not well integrated into the freeway management centers. Centers have incorporated traffic signal control by providing a workstation at the TMC/EOC for agencies controlling the traffic signals along with network access to the traffic control server and have attempted to facilitate a coordinated regional traffic signal system. This level of integration frequently requires management or interjurisdictional agreements.

Unique transportation context. Each TMC exists in a unique institutional framework involving jurisdictional boundaries, governmental organization, private organizations, operational policies and local and state laws. This topic was introduced as part of the integration conceptual framework. The unique context in which each TMC operates implies that the staff at the TMCs and cooperating regional agencies must design custom solutions to enable collaboration and cooperation.

Lack of national-level TMC coordination. TMCs across the country view themselves as fitting into a blend of three core functions: information clearinghouse, operations center, and/or emergency manager. This reflects the mixture of agencies and intra-agency departments that is unique to each TMC. The unique approaches to operations and integration contained in each TMC are not easily shared with other TMCs that may be facing similar issues. There is no TMC clearinghouse association that regularly brings together this varied group to discuss common interests. Therefore, cross-pollination and opportunities for TMCs to learn from other's experiences and practices are very limited. If such a venue existed for TMCs to share ideas it may facilitate addressing many of the challenges discussed in this report.

Consensus decision-making. In any situation where individual actors collaborate, some of the desired actions of one or each actor have to be abandoned to accomplish the joint goal. In the setting of a public agency, the loss of ability to act independently can significantly delay projects that a single agency would initiate immediately, and unwillingness to compromise can prevent the possibility of cooperation. Centers have developed both formal and informal working relationships to allow regional progress. Formal relationships take the form of intergovernmental agreements signed by the elected officials at the highest level and management agreements signed by managers of the involved agencies. Informal relationships take the form of working groups addressing technical and operational issues with each agency opting to send representatives based on their own best interests. Additionally, informal relationships form among managers and operational staff members who work together on a frequent basis.

Lack of reliability in legacy systems. Existing systems are not always designed to be robust with the occurrence of component failures or emergency situations. One single point of failure repeatedly identified in the study was the use of public infrastructure. The most common infrastructure system used by the TMCs is the commercial power grid. The second most common is dependence on commercial communications services including telephone service and the Internet. In the event of an emergency, traffic control devices, ITS field components, and communications to those devices are frequently affected by the emergency and not available for use during the emergency. TMC systems are susceptible to inoperability from lightning, wind, flooding, earthquakes, and deliberate sabotage as well as other events leading to outages in the public infrastructure. Centers that have addressed this challenge have implemented backup systems that do not rely on local infrastructure, such as satellite communication and backup power generators, and have upgraded the reliability of existing systems through retrofit or replacement.

Data security and privacy requirements. The legitimate data security concerns of law enforcement and homeland security organizations complicate the already difficult problems in data sharing. Depending on the agreements and processes in place, sensitive data may be completely unavailable for transportation uses, may have operational restrictions placed on them, or may require additional system development to implement filters to extract data that can be shared. Security issues increase costs and can impact timeliness of data sharing. Centers have addressed data security needs through cooperation among legal and technical staff members in planning the implementation. Some data security issues cannot be overcome without enabling legislative action.

Lack of benefits data and mature measures of effectiveness. In competing for budget and institutional resources, emergency transportation operations integration suffers from a lack of perceived benefit. In locations that have not experienced emergency situations recently, scarce resources for infrastructure investment are targeted to construction and routine operations. Even in locations that have experienced repeated emergency situations over the last decade, the perceived benefit from additional integration competes poorly against other infrastructure investments. One of the major weaknesses in advocating for integration is the immaturity of measures of effectiveness and benefit/cost analysis. To date, the lack of benefits data has been overcome by the actions of a local champion risking political capital and the willingness of one or more managers to initiate implementations without analysis support.

Licensing restrictions on proprietary products. Integration between centers using systems that are proprietary potentially faces licensing issues in sharing client software and access to custom protocols. Since many of the centers license software rather than owning it, the vendors of the software sell specific rights to the use of the software tailored to the institutional needs of the vendor. In some cases, the center has the rights to only use the software on a specific number of server and workstation computers. In other cases, the center has the license to an unlimited number of computers, but only on the premises of the center or only by agency personnel. In either case, additional licenses can be purchased, but with additional costs that may either not fit within center budgets or may be difficult to allocate between partner agencies. The ability to communicate with a system may require knowledge of specific message formats that are proprietary to the system vendor. In this case, the vendor may be willing to share the formats with an existing customer without additional fee, with additional compensation, or may consider the format to be vital to the company's competitive position making them unwilling to divulge the information at any price. Addressing this challenge requires knowledge of the licenses of existing systems and cooperation between managers and product vendors.

Differing legal bases for cooperating agencies. When centers cooperate with centers representing other agencies, legal barriers and potential liabilities arise due to the roles and legislated protection given to each organization. This also can arise when public resources are shared with private interests. This typically arises when a system or component installed for one purpose becomes used for an incompatible purpose, possibly a more critical role that the component may not be sufficiently hardened to accomplish in all situations. For example, a microwave communication system that is adequate for traffic surveillance video may not be sufficiently reliable for emergency vehicle communication use. This use could potentially expose the transportation department to legal proceedings if a citizen needing medical attention suffered harm due to the loss of communication between the dispatcher and the emergency vehicle. Centers addressing this challenge use a combination of coordination among technical resources, formal agreements among agency management, consultation with legal staff, and enabling legislation.

Lack of sustained investment in emergency transportation. Once a region has either experienced an emergency with serious transportation impact or observed a nearby emergency, the planning and integration process takes on significant urgency. If these efforts are successful, systems are implemented, processes are established, and staff is trained. Once systems and processes are established, significant resources are required to maintain both the staff and the systems in a state of readiness. Required expenses include repeated training exercises to keep knowledge fresh and the ability to retain or hire experienced staff. The observed "boom and bust" cycles of planning efforts reflect the reduction in emphasis that naturally occurs in contingency planning of any type. The decrease in effort is amplified in emergency transportation since most key managers and decision-makers have primary assignments outside of emergency transportation. Approaches to sustaining investment include dedicating staff or coordinators to emergency transportation and using champions to keep emergency preparedness as a priority. Sustained investment has been most successful where weather-related emergencies are frequent.

Insufficient funding. All centers identified available funding as a constraint. Most of the funding constraints limited staffing for either operational, management, or engineering activities. With additional engineering staff, more reliable systems could be implemented. With more management staff, improvements could be made either internally or in conjunction with cooperating agencies. With additional operational staff, improvements could be made in training and other aspects of readiness for emergencies. Centers that have succeeded in getting adequate funding have champions in government who vigilantly protect the center's budget and managers willing to make budgets for operations a priority.

2.3 ADDITIONAL CONCEPTS FOR EMERGENCY INTEGRATION

The best practices in this study reflect initial operating procedures available to operations staff positions in binders, in management offices, and condensed to flip charts. These documents were highly valued and reflect knowledge gained through years of experience. The experience gained through frequent interaction primarily with localized emergencies requiring response from local fire, rescue, enforcement, and public works staffs forms a basis for cooperation on all emergencies, no matter how extensive or extraordinary. However, the existing operations procedures were not comprehensive in terms of potential interacting agencies and with few exceptions, did not carry approval signatures from all of the interacting agencies.

During the study, the study team has identified a number of opportunities to improve TMC operations during emergencies that can be addressed by improved integration concepts. The issues that can be mitigated or resolved through integration include:

- Missing and inaccessible data supporting coordination among emergency agencies;
- Lack of clear communication with other emergency agencies;
- Inefficient introduction of emergency information;
- Reliance solely on intuition and experience from previous events; and,
- Inability to rapidly deploy resources to augment the existing system.

The team developed integration concepts to capitalize on these opportunities. Table 4 lists the integration concepts along with an assessment of the expenses related to pursuing the concepts.

Table 4. Cost Estimates for Integration Concepts.

	Costs			
	Research	Deployment	Operations and Maintenance	Management
Comprehensive coordination with all centers/all modes	Low	High	Moderate	High
Operational coordination/training with non-transportation agencies	Low	Low	Moderate	High
Optimized emergency information integration in TMC	Low	Moderate	Moderate	High
Advanced tool support	High	Moderate	Moderate	Low
Federal resources for rapid deployment	High	High	High	Moderate

2.3.1 Additional Application of Current Integration Concept

As mentioned previously, the current integration concept includes collaboration and cooperation based on sharing information to assist management and experienced staff. The concept of sharing information and decision-making can be extended further than is currently in practice. The extension of this concept can improve technical, physical, procedural, and institutional integration to resolve the problem of incomplete or inaccessible information being available to support coordination among agencies. Table 5 contains the current concept along with potential methods for improvement and some of the pros and cons associated with each concept/method combination.

Additional application of the current integration concept would culminate in the operations centers of all organizations active throughout emergency situations being tied together through a network of voice and data connectivity to coordinate the actions of each. From a TMC or TEOC perspective, connectivity would be provided with a limited number of Combined Emergency Centers (CECs) and as well as other organizations and devices not integrated into a CEC. Each CEC would collocate as many of the operations groups, managers, or representatives of organizations active in emergencies as possible into a single facility given the particular integration framework. Agencies without presence at CECs or with need for integration with other operations locations would be connected to the CEC via a reliable voice and data network. The reliability of the network could be accomplished through joint ownership, arrangement with public infrastructure providers, redundant media, or a combination of techniques. Physically remote centers, especially those representing smaller jurisdictions and those outside of urban areas, have unique challenges in obtaining reliable communication paths and acquiring systems that meet interoperability goals. A representative comprehensive network of agencies is presented in Figure 3. The centers and systems communicating with the TMC/TEOC exchange data of mutual interest. Data collected by the TMC and made available to other centers include video images, traffic data, infrastructure conditions, roadway network graphics, and incident data. Information collected by other centers and transmitted to the TMC include incident data, fleet resource availability, fleet vehicle locations, infrastructure conditions, press releases, press field reports, road weather data, weather reports, and weather forecasts. The fact that the central entity of Figure 3 is a traffic management center indicates that this study focuses on integration with the TMC, not that the TMC is the most important resource in emergency operations.

Significant improvements are available in the integration of emergency data during the recovery phase of an emergency. In current practice, DOTs generally coordinate infrastructure repair independent of TMC support. EOC operations typically are not structured for ongoing operations with significant information exchange with a TMC. TMC resources relevant to recovery include surveillance capabilities and public information capabilities. Surveillance includes existing video and traffic detection as well as infrastructure to expand the surveillance network on a temporary and rapid basis. Public information capabilities include media contacts, websites, variable message signs, and highway advisory radio.

A major enabler of increased integration is the ability of computer-based systems in use by each agency to exchange data rapidly and seamlessly. Based on the experience to date, interchange among systems from different agencies such as a DOT and a police department is enabled by use of widely accepted standards. Specifically, video images are easily exchanged using National Television System Committee (NTSC) and Moving Picture Experts Group (MPEG) standards. Electronic data on other topics such as traffic and incidents are enabled through the use of data processing and networking standards such as Ethernet, Structured Query Language (SQL), and Extensible Markup Language (XML). Starting in the late 1990's, FHWA has supported development of standards to enable the use of traffic and incident data for purposes other than immediate display. The IEEE 1512 family of standards addresses efficient communication between centers for the real time, interagency management of transportation-related events. Initial implementations of the standards are ongoing. Based on the data collected for this study, additional adoption of the standard and a broadening of the standard are required to limit the amount of custom engineering work involved in more comprehensive integration.

2.3.2 Currently Available Practitioner Improvement

In addition to the integration concept currently being applied, other improvements are available to TMCs without significant technological advances. Table 6 contains two concepts that can be implemented with existing technology along with potential methods related to these concepts and some of the pros and cons associated with each concept/method combination.

Table 5. Emergency Integration Concepts and Methods:
Current Concept Extension.

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Comprehensive center coordination	Deployment of redundant, survivable networks	Technical – Level 3	**Pros:** Improves willingness of emergency organizations to communicate over joint networks. Improves communications reliability, especially during non-routine operations. **Cons:** Entails additional engineering and deployment costs
	Exchange of recovery information	Technical – Level 2 to Level 3 Operational – Level 1 to Level 3	**Pros:** Improves efficiency of recovery efforts. Improves mobility in area during infrastructure repair and reestablishment of routine operations. **Cons:** Requires interagency staff priority in dynamic, high-demand situations
	Use of multi-industry data interchange standards	Technical – Level 2 to Level 3	**Pros:** Vastly reduces costs of data exchange between agencies **Cons:** Standards are currently insufficient in maturity and acceptance. May limit ability to address unique needs
	Champions for regional coordination	Institutional – Level 2 to Level 3	**Pros:** Enthusiasm of a champion, go to person **Cons:** Becomes another task among tasks for an individual that may result in limited effectiveness when competing responsibilities exist

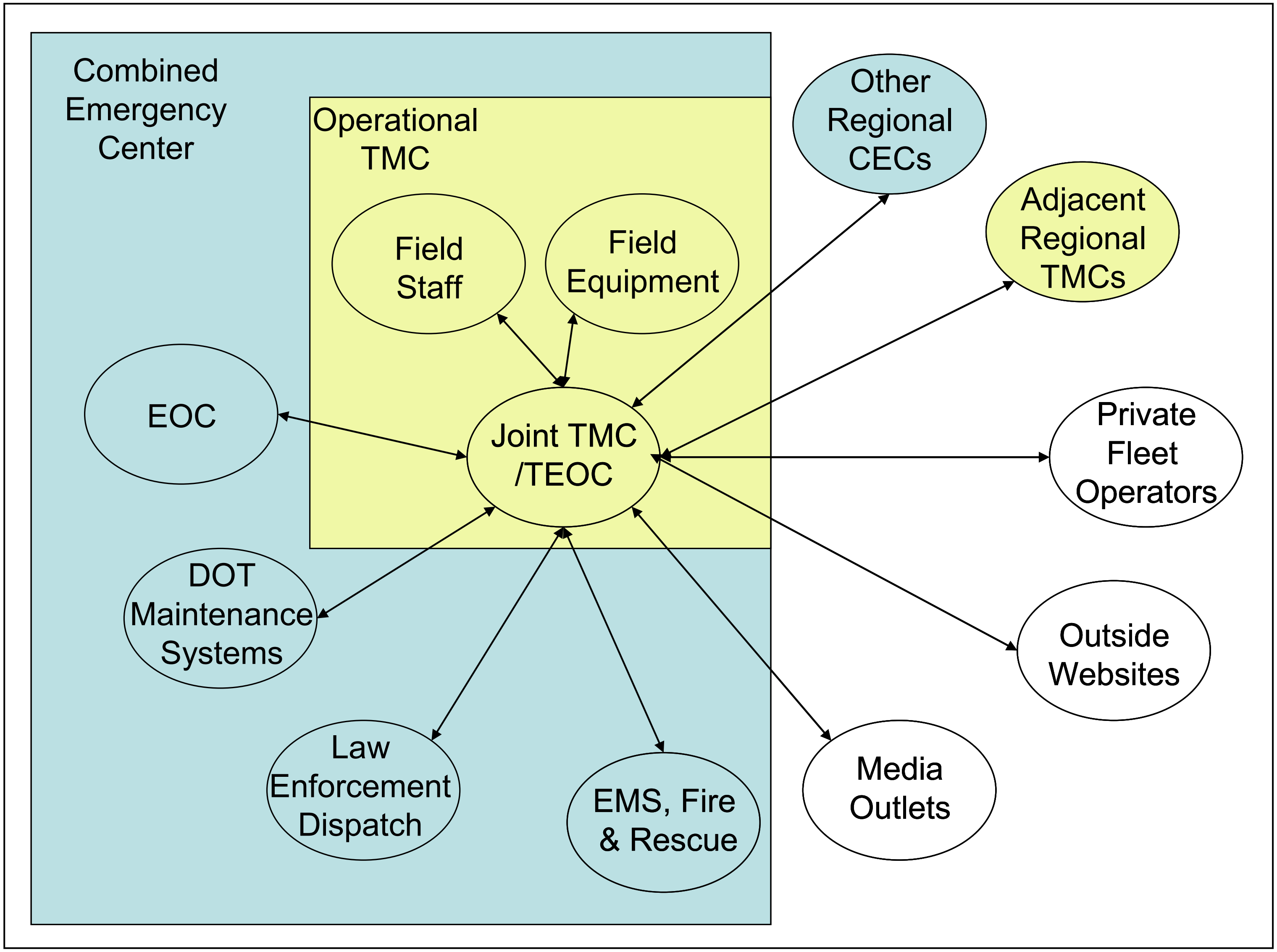

Figure 3. Representative Comprehensive Network.

Table 6. Emergency Integration Concepts and Methods: Available Concepts.

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Operational coordination and training	Training classes from FEMA on use of NIMS/ICS	Operational – Level 2 Procedural – Level 3 Institutional – Level 2	**Pros:** Improves integration with limited system development costs. Training opportunities readily available. **Cons:** Requires staff training outside of primary roles in routine TMC operations. Requires acceptance of DHS concepts.
	Champions for interdisciplinary coordination	Institutional – Level 2 to Level 3	**Pros:** Enthusiasm of a champion, go to person **Cons:** Becomes another task among tasks for an individual that may result in limited effectiveness when competing responsibilities exist
Optimized emergency information integration	Coordination using regional ITS architecture	Operational – Level 2 Procedural – Level 2 Institutional – Level 2	**Pros:** Based on established FHWA processes **Cons:** Field resistance to additional engineering and administrative requirements.
	Development of standard optimization process	Institutional – Level 2	**Pros:** Establishes useful process and cadre of experienced support contractors **Cons:** Requires extensive investment in development to assure process general applicability
	Development of MOEs	Institutional – Level 2	**Pros:** Provides basic technique for justifying and evaluating integration, which is generally recognized as an unmet need **Cons:** Requires extensive investment in development to assure adequate coverage and usability
	Use of systems engineering approach	Institutional – Level 2	**Pros:** Based on established FHWA policy **Cons:** Increased engineering and management effort required prior to project deployment. Field resistance to additional mandated processes

2.3.2.1 Operational Coordination and Training

Leadership in the Federal government for interoperation of emergency systems is coming from the Federal Emergency Management Agency in the Department of Homeland Security (DHS). DHS has established the National Incident Management System (NIMS) to improve interagency cooperation based on an all-hazards approach. The fundamental command and management component of NIMS is the Incident Command System (ICS), which provides a framework and command chain for on-scene incident response. In some cases, Multi-agency Coordination Systems such as EOCs and multi-agency centers coordinate with and support the on-scene incident command. Agencies that use Federal preparedness funds must adopt NIMS to retain funding eligibility. The schedule and process required for NIMS adoption is currently still evolving as are related standards and documents. While NIMS is not currently mandated for TMCs, agencies with which TMCs cooperate have incentive to begin NIMS implementation during FY2005, including institutionalizing ICS.

Transportation relates to several parts of the ICS organizational structure, which is shown in Figure 4. For DOT staff members on the scene of an incident, ICS specifies processes for fitting in to the overall incident response. Traffic plans for incident vehicles are produced by the Ground Support Unit of the Logistics Section and evacuation plans are produced by technical specialists in the Planning Section. Traffic management, which is not fully developed in current NIMS documentation, can provide valuable support to operations, planning, and logistics sections of the ICS organizational.

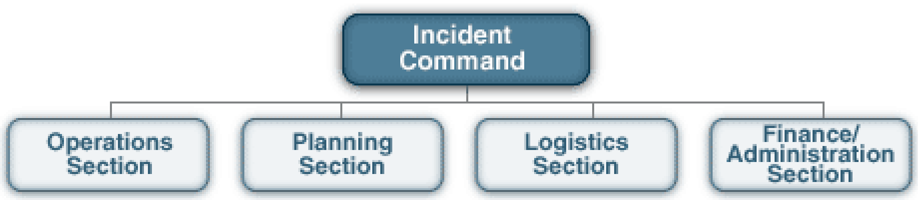

Figure 4. ICS Organizational Chart.

Training of TMC operational staff provides a basis for cooperation with all other agencies involved in an incident. Experience has shown that the ability to communicate clearly between staff members of the active organizations is a vital capability, with many of the failures in emergency operations attributable to poor communication. While localized emergency coordination is practiced on a routine basis, the interactions with some of the agencies in a regional emergency can be one-time events. This unique characteristic to emergency operations requires training and exercises to prepare the operational staff for a realized event. The variety of potential organizations that could be involved in the realized emergency necessitates training across the spectrum of agencies with standard training materials. The National Emergency Training Center operated by FEMA offers a series of classes related to NIMS and ICS. The training material and opportunities will expand as further protocols and standards related to NIMS are finalized. It is a recommendation of this study that introductory classes on NIMS be mandatory for TMC managers and operational staff members. NIMS courses are available on line from the FEMA Independent Study web site (http://training.fema.gov/EMIWeb/IS/).

In addition to classroom training, agencies in some of the centers studied participate in exercise programs with multiple agencies. The exercises range from tabletop exercises involving agencies routinely cooperating on major incidents to field drills such as "Top Officials" headed by DHS and "Determined Promise" headed by the Department of Defense that are extensively planned, involve thousands of participants, and attract emergency and political leaders. Cooperation on available exercises and drills should be accomplished under a NIMS framework. While the agencies are involved, the extent to which the operational staffs participate is extremely limited.

TMCs should coordinate operational concepts and procedures with cooperating agencies, both as identified under NIMS and as part of the recommendations from this study. To be consistent with the policy of FHWA and mandates of FEMA to cooperating agencies, TMC operations plans and procedures should be consistent with NIMS.

2.3.2.2 Optimized Emergency Information Integration

Progress toward integration has been accomplished through individual and some times heroic efforts of leaders in locations across the country, many of whom were interviewed in the course of this study. The integration came from a combination of foresight, political leadership, innovative funding, technical insight, and hard work. In transitioning from a process of innovation into a discipline with uniform excellence, rational processes are required. The rational process assesses the current situation, develops measurable goals and objectives, tracks progress toward those objectives, and then repeats the steps to establish a continuous improvement process. A typical optimization process is shown in Figure 5.

The establishment of a continuous improvement process is consistent with existing processes used currently, including regional ITS architecture development and a systems engineering approach. Such a process must be performed regionally given the unique integration context of each center. Federal support is appropriate both to develop resources for an optimization process and to support execution of the optimization process. Federal resources could include guidelines for process and staffing needs, model products, training material, and desired Measures of Effectiveness (MOEs). Federal support for execution would take the form of funding through grants and incentives.

Preparation and updating of regional architectures are now required for transportation projects. The regional architecture provides a forum for transportation and related agencies to review the existing and planned network of systems related to transportation. This process forms an excellent foundation for application of continuous improvement.

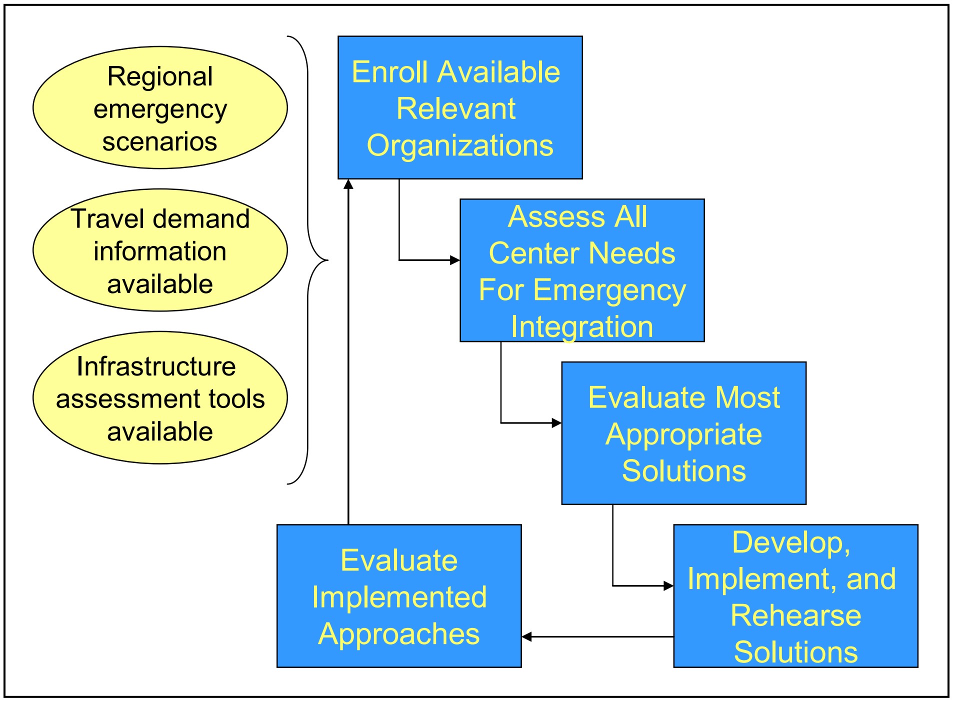

Figure 5. Optimization Process.

In preparation for the implementation of projects to improve integration, each region should perform a realistic self-assessment. The self assessment will identify needs and opportunities reflected in the regional ITS architecture. The assessment will also identify the capabilities and the resources available both within the region and from outside sources to address the identified needs. The assessment will realistically evaluate the feasibility of addressing the needs with available resources. One source for determining the feasibility is review of best practices from other regions addressing similar problems.

As part of rationalizing the process of optimal integration, projects should be implemented using a systems engineering approach. The systems engineering approach outlines steps to be performed and the ordering of the steps. An overview of the systems engineering process is shown in Figure 6. The systems engineering approach is progressive, with each document depending on the information shown in previous documents. The left hand side of Figure 6 shows system conceptual and design processes with increasing levels of detail. The right hand side of Figure 6 shows the steps in testing with increasing levels of completeness. The bottom of the diagram is the system implementation that ties the design processes to the testing processes. Testing of implementations is tied to specific design descriptions presented in a corresponding document. For example, requirements and architecture are at the same level as system verification and validation. The testing at the system verification and validation stage will substantiate that the requirements and architecture have been properly implemented.

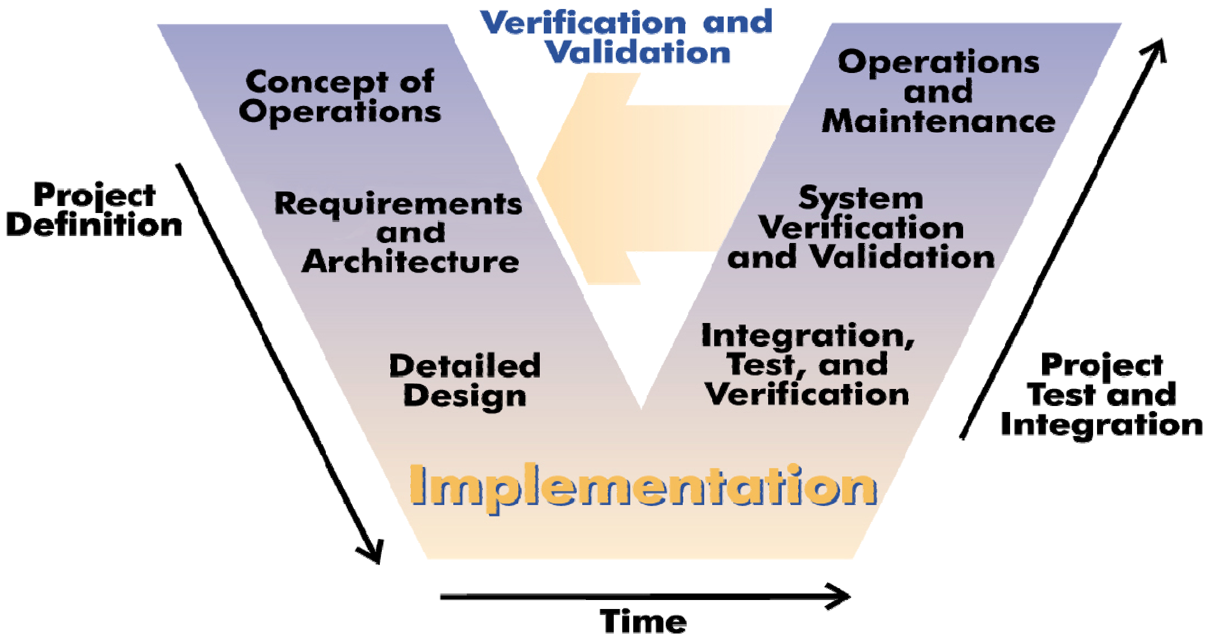

Figure 6. Systems Engineering "V" Diagram.

2.3.3 Research and Development Needs

The current state-of-the-practice provides a point of reference useful for TMCs pursuing further integration with other agencies active during emergencies. However, to move beyond the current state-of-the-practice will require an expanded vision and further investment in the development of new methods and approaches in emergency integration. Potential future methods may refine those found with existing concepts while others will likely be associated with new concepts. Table 7 contains two concepts that existing technology cannot support along with potential methods related to these concepts and some of the pros and cons associated with each concept/method combination.

A consistent theme of the research endeavors should be the establishment of management strategies and rules of practice to support improved TMC operations. Research funds should be identified and allocated to permit the research and operations communities to institutionalize practices that provide a clear, effective, and demonstrable management strategy to improve TMC operations through enhanced integration. These research studies should be utilized to identify common methods that cut across geographical and demographic scales and provide a constant measurement of the present 'best practices' and their evolution. As emergency traffic operations integration evolves, regular baseline investigations of the next level of best practices will continually provide a pathway for all TMCs to improve emergency operations.

Table 7. Emergency Integration Concepts and Methods: Future Research.

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Advanced tool support	Decision support research and development	Operational – Level 3 Technical – Level 3	**Pros:** Develops operational strategies and tactics beyond capability of human analysis in emergencies. Augments staff resources. **Cons:** Requires significant research and development to produce useful system. Conceptually immature.
	Joint federal/regional pilot projects	Operational – Level 3 Technical – Level 3	**Pros:** Allows demonstration of concept benefits with limited regional investment. **Cons:** No system approaching readiness for field test. Requires significant development effort with technical risks.
Federal resources for rapid deployment	Deployment of communication augmentation/ expansion	Technical - Level 2 Operational – Level 2 Institutional – Level 2	**Pros:** Addresses acknowledged lack of regional resources to deploy system with universal coverage and respond rapidly to extensive outages **Cons:** Technical difficulty to provide support for variety of fielded systems
	Deployment of field component augmentation/ expansion	Technical - Level 2 Operational – Level 2 Institutional – Level 2	**Pros:** Addresses acknowledged lack of regional resources to deploy system with universal coverage and respond rapidly to extensive outages **Cons:** Technical difficulty to provide support for variety of field devices
	Deployment of control center augmentation	Technical - Level 2 Operational – Level 2 Institutional – Level 2	**Pros:** Addresses acknowledged lack of regional resources to deploy comprehensive system and respond to outages of the primary center **Cons:** Technical difficulty to provide support for variety of fielded systems and regional settings
	Joint federal/regional pilot projects	Technical - Level 2 Operational – Level 2 Institutional – Level 2	**Pros:** Allows demonstration of concept benefits with limited regional investment. **Cons:** No system approaching readiness for field test. Requires significant development resources with technical risks.

2.3.3.1 Advanced Tools

During an emergency and recovery, emergency managers rely on their own cognitive skills to assimilate situational data and goals into plans of action. The manager's cognitive skills are conditioned and intuitive, based on experience, simulation, practice, training, reason, and knowledge along with situational awareness and the physical context. Existing tools are related to emergency transportation support planning, but are not designed for use during emergency operations. The tools used during emergencies come from the traffic manager's standard arsenal of surveillance, control, and public information systems, augmented by additional staffing.

The concept for advanced tools is to provide advice for actions that emergency managers can take to achieve transportation objectives in support of emergency management goals. The advanced tools would primarily aid technical integration. The advice would cover traffic operations parameters such as traffic signal timing, adjustment of traffic operations regime such as reversible lane operations, emergency operations decisions such as contraflow and evacuation, public information through both TMC devices and the media, and infrastructure repair priority. Such tools would synthesize real-time condition data from roadway sensors with travel demand measurements, condition of the available transportation network, and transportation objective representations into understandable recommendations to be selected by emergency managers. Sources of real-time data include traffic variables such as speed, volume, and occupancy, weather conditions and predictions that affect roadway capacity. The condition of the transportation network would include the roadway network adjusted for transportation management actions such as traffic signal timing and roadway availability. Transportation objectives relate to the transport desired by the emergency managers including emergency medical access, supply delivery to incident workers or a sheltered population, equipment movement to affect infrastructure repair, evacuation of a large population using private vehicles, evacuation of a population using a fleet of shared-ride vehicles or public transit vehicles, and return of an evacuated population.

To utilize such tools, emergency transportation managers would have to accept additional concepts including trip value, priority utilization of scarce vehicle and infrastructure resources, and system-optimal operations. The concept of trip value quantifies the benefit of each journey. Priority utilization of scarce resources addresses the constraints imposed by having a finite amount of transportation resources. For example, available roadway capacity across a bridge that acts as a bottleneck can be used by a family carrying three family members and their belongings fleeing an emergency, by a transit bus carrying 45 people with limited luggage, or medical supplies needed by the injured. System optimal operation describes a selection from the collection of resources to meet the objectives of system operation, even though some individuals may not be allowed to act in their personal best interest.

This type of advanced tool would require extensive research and development efforts prior to initial test usage. Initial test usage would require joint projects including regional and federal resources. With each emergency transportation operation being unique, expert support would be expected during the emergency events.

2.3.3.2 Federal Resources for Rapid Deployment

The concept of a rapidly deployable set of resources would provide any TMC the ability to field additional ITS components, communication networks, or control center components rapidly when an emergency occurs that exceeds local resources. This concept addresses primarily technical integration both within the TMC and with interacting agencies. The lack of local resources could be due to either gaps in the existing system that become important during the emergency or damage that occurs related to the emergency. In order for this concept to be viable, the reserve assets have to be able to work in any setting with any currently deployed system or to stand alone if the existing system is completely incapacitated or no system is deployed at the emergency location. The system would be deployed with the assistance of a federal emergency team, but the team would be under the direction of the local emergency managers and TMC managers with respect to deployment location unless the incident becomes federalized. Local management and operational staff would also remain in control of the fielded assets, including both the existing system and the temporary deployment.

The technical obstacles to achieving such a system will require significant development effort to overcome. The most difficult technical barrier to overcome is the variety of TMC systems currently deployed. Currently deployed TMCs are each essentially one of a kind. Unique requirements placed on TMC acquisitions mean that even when an implementer has an existing system available for deployment unmodified, the system is customized. Additionally, the fielded systems use a wide variety of field hardware ranging from the latest technology to devices that have been working adequately for decades.

Communications replacements are the most technically viable rapid deployment component. Existing technology for gap deployment or extensions allow connection of remote sites to regional networks without dependence on regional infrastructure. Connectivity options include satellite Internet services and trailer-based wireless Ethernet nodes. Products for conversion between Ethernet and many other protocols are readily available in the marketplace. Additional options are available if the communications device only has to cover a gap measured up to several miles.

Products deployed with each center present a more difficult technical challenge. Products fielded prior to the wide acceptance of NTCIP frequently have proprietary or custom protocols. For rapid deployment of systems components to work properly, the reserve assets would either have to communicate with the existing system or a conversion from the reserve asset's protocol to the existing system's protocol would be required. While this is achievable for components where a small number of companies set de facto standards with early implementations such as video surveillance, components without dominant companies present a difficult technical challenge.

Concepts for integration of additional center capability with existing systems that have not implemented inter-center communication are currently undeveloped. Developing concepts to establish meaningful integration poses a difficult research problem. The federal response assets should be consistent with the communication annex (ESF #2) of the National Response Plan.

2.4 RECOMMENDATIONS

The following sections discuss six approaches that the study team recommends be pursued to improve integration in emergency situations. The first four recommendations are available for immediate implementation with little or no technical innovation, either independently by existing TMCs or through leadership of FHWA. The remaining two recommendations are geared toward approaches that require research and development prior to being fielded.

2.4.1 Enhancements to Current Practice

The first four recommendations are focused specifically on enhancements to the current practice of TMC emergency information integration. Each of the recommendations provides specific actions either FHWA or TMC administrators can take to enhance the level of integration with the goal of improving the overall operational effectiveness of the TMC.

<u>Recommendation 1</u>: **Extend the current concept of collaboration and coordination to comprehensive coverage of agency centers and information**

Scope: TMCs should expand information sharing to a network including operations centers of all organizations active during emergencies.

Problem Addressed: Incomplete or inaccessible information required to support coordination among agencies resulting from limited technical, physical, procedural, and institutional integration.

Leadership: Transportation Management Center Administrators/Managers, regional agencies and organizations

Expected Outcomes: The expected outcomes of expanded information availability are an increase in the benefits currently being reaped including:

- Improved coordination and cooperation among agencies active in emergencies.
- Better decisions about the deployment of resources of each organization, including the TMC.
- More information of higher accuracy available to the media and the general populace.

Description/Approach: To date, emergency integration has occurred on a case-by-case basis using the foresight and resources of individual centers. This process can be continued to add relevant agencies to the integrated network as identified by centers working in their own distinct contexts. While leadership for implementing this recommendation ultimately rests with the centers on the front line of integration, FHWA can enable improvements by continued support of standards development applicable across industry boundaries and through education of best practices using traditional techniques such as scanning tours and peer-to-peer networks. FHWA can also enable advancement in the state of the art through funding support.

<u>Recommendation 2</u>: Improve coordination capabilities of operation staffs

Scope: TMCs should develop interagency operations procedures and participate in joint education and training covering response to incidents of all scopes under the National Incident Management System framework

Problem Addressed: Inability to coordinate and communicate effectively among members of operational staffs of various agencies.

Leadership: Transportation Management Center Administrators/Managers, regional agencies and organizations.

Expected Outcomes: The expected outcomes of improved coordination are:

- Improved effectiveness of operational staff members at an incident scene.
- Avoidance of communication errors and thereby a reduction in exposure of emergency responders to life-threatening.
- Improved coordination of center and field staff members

Description/Approach: The improvement of coordination among operational staff members can be accomplished with existing resources. Training opportunities in the use of standard tools such as NIMS are available under the sponsorship of DHS both in online and classroom settings. The performance of exercises to reinforce and institutionalize the training can be accomplished through interaction with regional agencies and coordination with Federal agencies with presence in specific regions. FHWA can support this recommendation through education and training grants, sponsorship of joint training exercises through the National Highway Institute, and raising awareness of the need for improved operation via resource centers.

<u>Recommendation 3</u>: Develop quantitative measures of emergency integration and emergency operations

Scope: To make rational decisions and discuss trade offs for use of limited resources, decision makers need quantitative terms for use in analyzing the benefits of emergency integration. MOEs should be developed that address effectiveness of integration, effectiveness of operations, and risk exposure for the emergency transportation need

Problem Addressed: Integration takes place based on non-technical factors leading to inefficient improvement in integration and operations.

Leadership: FHWA with support from Transportation Engineering groups such as the Institute of Transportation Engineers and the Transportation Research Board.

Expected Outcomes: The expected outcomes of an availability of quantitative measures include:

- Improved ability to analyze emergency integration and operations capability;

- Improved cost effectiveness of integration improvements; and,
- Improved management of projects and programs.

Description/Approach: FHWA has taken leadership roles in the development of transportation performance measures that can be widely applied and understood using a combination of review of performance measures currently in use, analysis by experienced transportation researches, and review by transportation practitioners. The emergency transportation operations field lacks performance measures related to integration or operation to support decision-making and to guide research. FHWA should initiate a line of research to address appropriate ways to measure the performance and effectiveness of emergency transportation similar to the efforts related to broader transportation measures.

Recommendation 4: Establish an optimal level of integration at each TMC and in each region

Scope: TMCs should rationalize the process of establishing increased levels of integration.

Problem Addressed: Integration takes place based on non-technical factors leading to inefficient improvement in integration and operations.

Leadership: Transportation Management Center Administrators/Managers, regional agencies and organizations with FHWA support.

Expected Outcomes: The expected outcomes of an optimal process include:

- Improved cost effectiveness of integration improvements;
- Establishment of quantifiable evaluation and effectiveness criteria; and,
- Improved management of projects and programs.

Description/Approach: Optimization processes use impartial evaluation criteria to determine the best use of available resources. A continuous improvement paradigm, such as the one shown in Figure 5, repeatedly applies evaluation and implementation to approach optimal improvement. Application of such an approach requires management and technical resources. While TMCs may perform evaluation on their own initiative, FHWA should encourage use of such processes by incorporating evaluation and feedback requirements into mandates for use of systems engineering approach and National ITS Architecture usage. FHWA should also enable optimization processes by developing a model process and applying it through a model deployment.

2.4.2 Supporting Research

The following two recommendations outline research and development needs that would extend the state of the practice in emergency integration. These recommendations present needed improvement in technology to enable the accomplishment of the concepts being supported. If successful, the process of creating this technology will cause the concepts to evolve and mature into products that can be field tested and placed into operational use.

<u>Recommendation 5</u>: Develop advanced decision support tools

Scope: FHWA should sponsor research into advanced tools to assist emergency transportation managers is making strategic and tactical decisions.

Problem Addressed: Decisions made during emergency and recovery operations are limited by the experience and cognitive capacity of managers and operational staff.

Leadership: FHWA supported by research institutions.

Expected Outcomes: The expected outcomes of advanced tool use include:

- Increased capacity to integrate relevant data from multiple locations;
- Reduction of cognitive load of emergency transportation managers;
- Capability to implement complex calculations and algorithms in support of emergency decision-making; and,
- Ability to capture knowledge of most experienced emergency transportation managers nationwide.

Description/Approach: Knowledge of approaches for the use of automated or computational tools to assist in emergency transportation operations is limited. Basic research is needed into the processes in emergency operations that can be assisted through advanced techniques. The initial research goals should relate to analysis of the emergency transportation process to identify areas where additional integration can be advantageous, identification of potential sensing and computational techniques that can improve operations and management, and estimation of potential benefits to implementation of advanced tools. The FHWA should sponsor research at research universities and institutions to both formulate the research goals and perform the research.

<u>Recommendation 6</u>: Develop emergency resources available for rapid deployment

Scope: FHWA should sponsor research into development of assets available for rapid deployment when needed in a region experiencing an emergency situation.

Problem Addressed: In emergencies, the deployed transportation systems in a region may be temporarily disabled or insufficiently extensive.

Leadership: FHWA supported by research institutions.

Expected Outcomes: The expected outcomes of rapidly deployable resources include:

- Decreased duration of outages caused by emergency occurrence such as storms, power outages, or deliberate targeting of infrastructure.

- Reduction in regional resources dedicated to rarely used functions.
- Improved ability to handle region-wide or multiple region incidents.

Description/Approach: Significant natural and manmade disasters can introduce gaps in coverage or complete outages in even the most robust of systems. The ability to augment, repair, or completely replace a network with communications, center, or field components can greatly improve the capabilities of emergency transportation operations. The major technical hurdle to overcome is the incompatibility between the currently deployed systems, most of which are essentially custom systems using a wide variety of current and obsolete components. FHWA should initiate research into the ability to develop a pool of resources available that can interoperate with all deployed systems. This research includes both discovery of the full set of fielded devices and the development of approaches, techniques and products that will restore or expand any system. Appropriate research institutions include both transportation organizations and electrical engineering institutions.

2.4.3 Federal Roles

Transportation operations are state, regional, and local responsibilities. Federal roles provide support to operations through a combination or techniques to advance technology, deployment and operations. Many of the Federal roles have been referenced in the recommendations in the previous section and are presented in more detail in this section.

The single constraint faced by all locations is funding. Budget pressures require the TMC to compete for resources with other beneficial projects. While cost/benefit analysis is helpful, the realities of assembling a city, state, regional, or facility budget put each additional capital and operating expense under scrutiny. The federal roles in funding are to create incentive through grants, pilot projects, and rulemaking to assist integration projects reach deployment.

Additional ways to quantify the impact of integration are needed. Neither MOEs, which quantify effectiveness of an approach to meet an objective, nor Measures of Performance (MOPs), which quantify the level of usage of an approach, are mature and institutionalized in the Emergency Transportation Operations arena. The current lack of MOEs limits the ability for emergency transportation integration projects to survive the budget processes. The federal role in developing measures is to lead the process of both defining the measures and providing expected values.

For concepts that require significant research, federally sponsored studies will be needed to advance technical knowledge. The advanced tools and rapid deployment resources require investment beyond the capability of regions to perform, with implementation and benefit years from achievement.

The traditional FHWA role in providing technical advice is needed on several technical topics related to integration. Dissemination of best practices related to integration would assist regions in several aspects of the existing and new integration concepts. With the evolving standards and identified need for additional multi-industry communication, federal effort is needed to track and influence standards development efforts. Federal support to identify promising new technology is valuable to regions. Training opportunities related to the best practices, standards, and technology are needed to assist regions, with a foundation in NIMS being desirable.

Once research and technology are developed to the point where beneficial implementations are feasible, federal support of demonstration projects becomes important. With the highly technical nature of initial implementations and the inherent budgetary and technical risks, regions will more quickly move to adopt the concepts with a federal partner assisting in the implementation based on national priorities. The technical nature of implementations also will necessitate a federal role encompassing operations and maintenance as well as initial implementation.

[8] Department of Homeland Security. 2004. *National Response Plan – Transportation Annex.* (December).

3. INTEGRATION FOR WEATHER

3.1 OVERVIEW

Weather often impacts efforts of transportation system operators working to maintain safety and mobility. Making sense of weather information along with recognizing the benefits of its application beyond the simplest case is not a trivial task. As a generalization, TMC operators tend to be more responsive and take action based on their observations of traffic flow rather than responding directly to weather information. TMC personnel frequently lack critical weather information and the needed procedures to incorporate weather information into effective decision-making to improve the efficiency of traffic operations.

> Weather integration in a TMC will enhance the ability of operators to manage traffic in a more responsive, effective way.

The study of select TMCs has shown that the integration of data and information across multiple agencies and organizations is beneficial to a TMC to the extent that it allows the TMC to conduct its operations more effectively. The exchange of weather information provides an opportunity to draw agencies or elements within a given agency together more effectively. Fortunately, as weather data and decision support systems evolve and become integrated into the operations of more TMCs, weather-responsive traffic management will become more widely adopted as a standard practice.

It is important to understand how weather integration at a TMC can enhance its operation. Prior research has proposed that "weather-responsive" traffic management strategies can be planned and implemented to more effectively address and mitigate weather effects on traffic flow.[9] This implies that the TMC as the primary traffic manager is able to control or alter the traffic in a manner to prevent, reduce or eliminate the effect that weather would otherwise have on the traveler to the same degree that it can be done in congestion situations. However, weather impacts traffic to differing levels across the nation, and the level of weather integration may vary from one TMC to another. The decision of how much weather integration to implement is a process that involves careful consideration, assessment, and planning.

It is clear that weather has major and minor impacts on transportation management operations. More typically these are minor impacts that result in reduced traffic flow or increased minor traffic incidents during seasonal weather conditions. At other times weather can have a major impact on transportation management operations. Natural weather disasters (e.g., hurricanes, winter storms, and severe summer storms including flash flooding, that severely affect large areas) typically cause the greatest disruption to transportation systems. During these events major routing changes, dramatic traffic bottlenecks or a complete urban, statewide, or regional transportation system shut-down are likely to occur.

Figure 7. Precipitation Causing Traffic Congestion and Delay.

An example of a typical weather impact involves the precipitation accumulating on an urban highway network (Figure 7 shows a photograph of traffic congestion during a snow event where heavy snow has accumulated on an Interstate highway. Whether this is a snowfall in Minneapolis or, light rain in San Diego it results in travel delays and enhanced congestion as travelers respond to changing road surface conditions and levels of mobility. Often these conditions are exacerbated by motorists failing to respond to the changing conditions, resulting in crash incidents that further impede traffic flow.

The occurrence of a hurricane landfall is an example of a weather event that has a major impact on TMC operations. A classic example of this impact occurred during Hurricane Floyd in 1999. The resulting pre-storm evacuation and the associated transportation system impacts were significant and included massive traffic delays, congestion and incidents (Figure 8 is a photograph of highly congested contraflow operations on a four-lane freeway. Further, the extraordinary inland flooding resulting from excessive tropical storm rainfall across a vast portion of the Atlantic seaboard extended the transportation operations difficulties well beyond the hurricane's landfall.

Figure 8. South Carolina Contraflow Operations and Congestion Associated with Evacuation Ahead of Hurricane Floyd.

Weather information that could assist TMC operations comes in many different forms. Generic weather information, such as what you would find on various local and national public television and cable weather news sources, provides a broad view of weather conditions for a very general audience. Other forms of weather information including those available from commercial weather service providers are available that target the surface transportation decision maker with tailored weather information specifically designed to assist the traffic manager. Although the generic weather information can be of some help to TMCs, it is very limited. Moving from generic products to more tailored weather information providers will increase the effectiveness of integration activities discussed in this report where this information is appropriately incorporated within the decision making process.

Another aspect of weather information that needs careful understanding is the accuracy of the weather data and forecasts. It is not enough to say that "weather information", when integrated into a TMC, will assist with decision making. Weather data and forecasts used by traffic managers need to be accurate to be useful. However, weather forecasting in its current state-of-the-technology is an inexact practice and often the weather observations used to generate forecasts and for use within TMC operations are inaccurate to varying levels. Therefore, it is important during the integration of weather information into a TMC to develop methods of routinely reviewing the quality of the all weather information. Procedures should exist to ensure that observed data are representative of the current weather conditions. Just as important, methods of monitoring the accuracy of weather forecasts are needed to keep the best possible information available for decision making. Over the past decade, new weather data monitoring and weather forecasting methods have been developed that are now used to support operational aspects of surface transportation. However, surface transportation weather analysis is still a young science and research continues on this topic.

The potential to reduce or avoid the impacts of weather on transportation system operations provides the rationale for improved weather integration within TMCs. The process by which this occurs is greatly facilitated through both the identification of concepts, or *ideas*, by which effective and optimal integration may occur and the methods that show *how* the concepts can be realized and effectively implemented. The concepts that provide the most effective pathway for integration for a particular TMC will depend upon the needs and issues central to a specific transportation network. However, the success of any weather integration effort must begin with solid concepts that describe *what* integration looks like in a particular TMC application. Several broad concepts of weather integration and associated methods to achieve these concepts are discussed in Section 3.2. These broad concepts present a wide-range of possible weather integration from improved awareness of weather to making the TMC the focal point for weather information.

Often the most effective weather integration will result in the incorporation of weather data and information in a non-intrusive manner into existing TMC operations. These data and information can exist in a background state during periods when fair weather dictates that minor weather impacts on traffic will exist. As integrated weather information systems identify a growing risk of impact on transportation systems, the weather information moves to the forefront of the TMC decision-making process.

Methods of integration reflect an action that builds upon a concept and describes *how* a particular concept of integration can be achieved. Applying a method to achieve a concept of integration requires the full spectrum of assessment, planning, and implementation strategies. For some methods the effort involves the procurement of services that support more effective utilization of available weather data within the TMC. This method of effective utilization will vary with TMCs and is http://www.henryart.org/exhibitions.htmdetermined by local requirements. For some the methods could involve the use of custom surface transportation weather services that provide notification of specific road weather hazards at discrete short time intervals that address defined support requirements for the TMC. Others methods could actively integrate weather and traffic management through the development of sophisticated new products that use computer modeling of traffic volumes by incorporating short-range, site-specific weather predictions of the roadway environment. Other methods may result in a growth in personnel commitments within the TMC to routinely facilitate the incorporation, analysis and exchange of weather information with other operational aspects of the TMC.

The effort to identify concepts and apply methods of integration is facilitated by reviewing the current state-of-the-practice and establishing a relationship between what exists in the practice with the local needs of a TMC. The process of using 'lessons learned' improves the communication of experiences and diffuses these lessons learned to others in the transportation management community. Ultimately, the incorporation of emerging technologies and procedures for weather integration will result in a 'next generation' TMC that incorporates the best the state-of-the-art will permit.

A significant part of the success of effective and efficient weather integration will depend upon the availability and acquisition of more accurate weather data and forecasts by the TMC. This will require growth within the surface transportation weather community to provide improved weather support services including the innovation of more tailored weather data and products supporting TMCs. However, to achieve effective and efficient weather integration within TMCs, it will be necessary to change existing operational paradigms, modify present TMC cultures, and promote greater levels of weather integration through the various dimensions of integration. Recommendations for improving current practices and the identification of future research (described in Section 3.3) are important aspects in the overall process of improved weather integration within TMCs.

3.2 STATE-OF-THE-PRACTICE

The state-of-the-practice in weather integration, as observed in the site visits under this study, is illustrated by a set of core integration concepts and associated implementation methods. The implementation methods range in sophistication (in terms of levels of effort) from fairly simple to very detailed. In addition to what the study team observed, potential future concepts and methods are identified. This section describes integration strategies being used today, best practices observed at selected TMCs, and the weather information integration concepts and methods characterized in terms of integration levels and their advantages (pros) and disadvantages (cons). Additionally, this section discusses the challenges of weather information integration from extensive interactions with TMC managers during site visits and other discussions.

3.2.1 Operational Strategies In Use at TMCs

> Current and future weather information integration in a TMC is dependent on the institutional landscape, weather exposure, transportation infrastructure, and weather information needs in the state or region.

It is important to consider what traffic management decision options are available within a specific TMC when evaluating its level of weather information integration. A current concept of weather-responsive traffic operations incorporates three mitigation strategies: *advisory, treatment,* and *control.* While mitigation addresses one way TMCs use weather information in their operational strategy, this study suggests that in addition to mitigation there are two other operational strategies used by TMCs in support of weather information integration: *sourcing* and *analysis*. In operational terms sourcing relates to how the TMC acquires the information needed, and analysis relates to how the information is applied to current and forecast traffic and road conditions. This section discusses these three operational elements of weather information integration.

Mitigation: Of the three mitigation strategies, advisory is the most widely practiced and integrated. Here advisory not only addresses the users of the transportation system but the operators as well. The following are some examples of this:

- TMC staff are better informed and prepared for traffic operations and incident management when they are provided with advanced, detailed, and route-specific weather and road condition information. TMC operators also were able to provide more timely and accurate information on expected conditions to travelers over Dynamic Message Signs (DMS), Highway Advisory Radio (HAR), 511, and web sites.
- Users of the transportation system are better informed and advised through the adjustment of DMS messages or implementation of variable speed controls. The weather information used for this comes from:
    - various weather sources, including generic and tailored weather information,
    - direct observation of weather conditions,
    - verified travel and road condition reports, such as lane closure, limited visibility, or reduced road friction taken from direct field reports,
    - Environmental Sensor Station (ESS) interpretation, or
    - traffic surveillance equipments including CCTV.
- TMC operations changes can be made for staffing levels and preparation for increased or different types of traffic incidents based on weather information gathered.

Treatment, as a mitigation strategy, is directly related to applying resources to the physical infrastructure in order to alter the effects of weather on traffic and is supported by the integration of roadway maintenance activities within the TMC. In all cases observed in the sites visits, maintenance departments have the responsibility for determining when and where to pre-treat or plow roads during winter weather. In integrated cases, the TMC either provides weather forecasts to maintenance personnel or updates maintenance personnel with reported road conditions and CCTV image interpretations. Co-location of maintenance within a TMC or having maintenance staff in the TMC during times of intense weather events improves the maintenance supervisors' "big picture" view of impacts throughout the region. Also, maintenance's perspective and information offer commensurate benefits to TMC operations.

The third strategy, control, reflects how TMCs manage or regulate traffic flow through, for example, variable speed signs, traffic signal timing, or contraflow systems. Control actions are usually taken in response to observed changes in traffic conditions, due to weather or other causes, but could also be taken in anticipation of weather impacts.

Sourcing: Observed success at these TMC sites for weather information integration into traffic operations appears to depend significantly on the continuous and up-to-date source of weather information (tailored to the surface transportation decision makers) operating in the background of traffic operations. Specifically, this relates to the accuracy, content, appropriateness, and availability of the information. As the forecasted weather event materializes and conditions become more critical, there is a seamless and efficient escalation from background information to a primary information source consistent with the types of decisions or activities that need to be taken by the TMC as part of their "standard" operations.

Analysis: At each of the sites visited, analysis strategies were illustrated by the way in which the TMCs integrated, in various ways and at various levels of sophistication, weather information (generic and tailored) into their operational procedures to better prepare for forecasted weather conditions and the likelihood of incidents relating to weather. Analysis strategies are where weather information integration has the most visible impact and potential for improving operational efficiencies. Many of the concepts and strategies described below in this report are directly related to analysis strategies aimed at effective use of weather information.

One example of this can be seen in how each of the sites relies on various approaches to help them become aware of weather issues, thereby relieving the TMC staff of the necessity for continuously analyzing the weather. "Weather triggers" are used to notify TMCs when threshold weather events have developed that require TMC staff action. The specifics of the weather triggers are established through an analysis of local weather features critical to the TMC operations, often from an historical perspective of past situations when the TMC has had to respond to weather events. These "weather triggers" may include:

- general weather forecasts expressing significant weather changes and/or precipitation,
- a "heads-up" call from a private weather service for tailored road weather conditions beyond a threshold,
- alarms such as the Flood Emergency Warning System (FEWS) and Automated Local Event Reporting in Real Time (ALERT) systems, or
- activation of the Emergency Operations Center (EOC) or escalation within the organization of regional emergency control centers that involve the influence of weather.

An important study finding was that the level of desired or attained integration appeared to be directly related to weather type, complexity, or potential incident severity. That is, the greater the number of regular occurrences of varied types of adverse weather, the more involved the integration effort. TMCs that faced infrequent occurrences of a single type of adverse weather needed less analysis and tended to exhibit lower levels of integration. This further illustrated the role that event exposure (one of the determinants shown earlier in Figure 1) plays in determining the level and nature of integration adopted at TMCs.

Integrated Operational Strategies: Some examples of operational strategies observed at the TMC sites visited and the uses of weather integration are illustrated below:

- TMCs typically make their decisions and take actions based on traffic information from CCTV traffic surveillance, volume and speed detectors (incident detectors), 911 calls, and other incident reports. Weather can affect the traffic, and if the traffic's response to the weather is not consistent with the TMC's expectations, then the TMC responds to the changes observed in traffic.
- Each of the sites has a central weather information core. This is a source of continuously updated weather information operating in the background and always accessible. The sophistication of this source is typically governed by what the organization considers adequate and affordable. The information sources range from a constant display of television cable weather to a weather operations group collocated with the TMC organization.
- Two approaches are associated with the technical integration of weather information:
    - One fundamental approach is visualization of information, e.g. constant display of weather radar or weather satellite images. This allows operators to see where adverse weather may be developing. Visual verification of traffic and traffic response to weather is relied upon to assess the consequences of the weather.
    - The second fundamental approach is the combination of observations from a variety of subsystems, visual and non-visual, such as visually made road condition field reports and ESS data.
- The content, reliability, and accuracy of weather information utilized by a TMC can vary. These factors express a measure of quality of weather information and underscore the diverse sources and utility of weather information. There is a difference between the summary information that is provided by a TV station weather forecast and the location and time-specific information that can be offered by a surface transportation weather service provider. While the former is readily available at little to no cost to TMCs, the content and accuracy is not controlled by the TMC, and this reduces the reliability of the information source. This is true for all sources of public weather information that are obtained by TMCs. However, through custom weather service providers, more specifically those specializing in surface transportation weather services, the content of the weather information is most often tailored to the TMC's requirements and provided under contract for services. This provides the TMC the opportunity to control the quality of weather services through performance requirements. In this manner the TMC can maintain better the level of content, accuracy, and reliability to support its operation mission. With this control on quality the TMCs can promote more effective integration

through coupling high quality data and knowledgeable operators who can interpret and apply the information. However, the effective integration goes beyond the quality of information available to the TMC. Establishing knowledgeable operators requires a level of sophistication that ensures their ability to utilize the information they are provided.

3.2.2 Observed Best Practices

The current weather information integration concepts and methods in practice at TMCs across the country reflect the regional and local determinants of integration for a particular TMC, as illustrated earlier in Figure 1. Therefore, a concept and method combination that is appropriate at one TMC may not work effectively in another. During the site visits, the study team observed several successful applications of weather information integration concepts and methods. A set of best practices was identified from observations and discussions with TMCs employing the most advanced weather information integration approaches in the country. These best practices were documented in Chapter 5 of the Baseline Report (Appendix A) and are conveyed within the concepts and methods discussed below.

Table 8 summarizes these best practices and the locations where they were observed. It should be noted that these practices may also be implemented in other TMCs nation wide. The TMCs listed here are from the study sites visited.

3.2.3 Concepts and Methods

Concepts and methods of weather integration in transportation operations reflect a forward-looking use of current technologies, coupled with enlightened management support among participating agencies, for each of the five integration dimensions (operational, physical, technical, procedural, and institutional). These concepts and methods represent examples of the various levels of integration supporting transportation operations across the country today. They serve as examples of effective operations for others to emulate and adapt to their particular needs and conditions.

Table 8. Weather Information Integration Best Practices and Observed Implementations.

Best Practice	Locations	Observed Implementation
Continuously updated and available weather information with threshold-determined automatic notifications of weather-related issues	Salt Lake City	Partnership between a surface transportation weather service provider and dedicated statewide weather operations group that provides a natural flow and alertness to weather conditions
	Pennsylvania Turnpike	Scheduled reports around the clock from the field and constant display of the weather radar images for each segment of the turnpike across the state
	Houston TranStar	Flood gauge map and alarm system
Seamless combination of observations from multiple information sources and subsystems	Maryland CHART	One GUI of ESS information from the RWIS server, vendor-provided surface transportation weather forecasts, and weather remotely-sensed imagery from another vendor
	Salt Lake City	Integration of ESS data from three ESS servers, and incoming road condition and restrictions in the ATMS operators system management GUI
Geographic visualization of weather information	Cherry Hill, NJ	Magnetic whiteboard map for maintenance to track and organize their snow-fighting efforts
	Salt Lake City	An Internet GIS-based webpage showing the driving impacts of weather and or restrictions on specific route segments throughout the state
	Houston TranStar	Automated wall map with warning lights for each of the flood gauges presents current thresholds and is replicated on the network with GIS software
Specific integration procedures directly related to the primary type of weather issues that affect traffic in a region	Houston TranStar	The power to the light rail is shut off automatically when water depth reaches a certain threshold near a transit underpass
Weather information used by emergency management personnel to monitor potentially dangerous situations or safely dispatch emergency responders	Austin	Determining how to route a helicopter air ambulance around localized thunder cells
	Houston TranStar	Relocating heavy towing vehicles to be ready for flooding conditions and alteration of transit routes due to anticipated underpass flooding

Table 8. Weather Information Integration Best Practices and Observed Implementations (continued).

Best Practice	Locations	Observed Implementation
Traffic operations data used by maintenance staff and weather forecasters to confirm conditions and improve responses	Salt Lake City	The weather operations group (collocated in the TMC) use CCTV images and road condition reports from traffic operations to confirm weather conditions and refine forecasts provided to statewide maintenance dispatchers (also located in the TMC)
	Los Angeles	Major traffic incidents identified and tracked by traffic operations personnel were provided to collocated maintenance dispatchers who deployed incident response teams
	Minneapolis	Maintenance monitors the traffic system during traffic management off-hours using the CCTV and other ATMS tools as weather information sources
	Maryland CHART	Maintenance is nearby the control room and, when they are not present in the room, they are regularly apprised of the effects seen on the roadways due to weather
	Cherry Hill, NJ	The entire TMC system shifts and the ATMS tools present in the control room (CCTV) become some of the key sources of weather information
Use of quick-reference flip Cards on operation's workstations	Salt Lake City; Minneapolis	Both locations employed quick-reference cards containing specific information related to field conditions that require response, criteria for contacting service providers, summary operational actions or checklists, and contact numbers

The following seven weather information integration concepts are the result of observations and research conducted by the study team:

- **Weather information coordination** – the management of weather information in a TMC and how it is, or may be, integrated.
- **Continuously available weather information** – an automated process or other robust structure in place at the TMC to bring weather information to the attention of those who can benefit from it.
- **Automated thresholds or escalation notification** – an automated notification system that triggers a weather situation alarm to notify operators of a developing and potentially dangerous condition.
- **Seamless integration of multiple sources and subsystems** – primarily a technical approach that assists transportation operators to perform their tasks by automating the

manual collation of weather and traffic related information from multiple sources or in disparate forms.

- **TMC provides the operations center and administration and serves as a clearinghouse for weather information** – weather information such as RWIS, ALERT, FEWS, and 511 is in-house in the TMC and readily available at all times to aid with data management and interpretation.
- **Community awareness between the TMC and weather communities** – a form of institutional integration that brings together these two communities and enables the learning and enriched application of weather information use in the TMC.
- **Decision Support** – an evolving integration concept that will in time provide automated support to TMC operators based on a set of proven approaches to assist with transportation operation decision-making during, or prior to, weather events.

Table 9 lists each of the concepts, along with their associated methods and some of the pros and cons associated with each concept/method combination. The information identified in Table 9 represents the primary findings of this study that are referenced in subsequent sections of this report. Table 9 generally orders the implementation methods in terms of increasing levels of integration, with the highest levels representing the best practice associated with that concept. However, because integration is understood as a multi-dimensional concept, it is often not possible to clearly rank each method unambiguously in a linear fashion. Nevertheless, the methods shown in Table 9 on the bottom of each list tend to reflect a better form of integration than those on the top of the list.

The specific application that is appropriate for a particular TMC will depend on their self-assessment of several factors including the institutional landscape, weather conditions, transportation infrastructure, and weather information needs. So as not to be too prescriptive, the methods identified in Table 9 are provided at a fairly high level of detail. It is purposefully left to each TMC to evaluate which concepts and specific methods will work best for them in meeting their needs.

Each of the concepts identified in Table 9 was observed in at least one TMC during the site visits. In most cases several methods were implemented in association with each other to maximize the benefits of weather information use in decision-making.

Table 9. Weather Integration Concepts and Methods.

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Weather information coordination	Intra-TMC committee tasked with weather information coordination	Institutional – Level 2	**Pros:** Good beginning. Can initiate the needs analysis process, utilizes minimum additional effort, intra-TMC coordination essential for institutional integration. **Cons:** Will not address improvement beyond a limited need if the weather events or traffic situation have any level of complexity, high frequency, or severity.
	Identified TMC or maintenance staff member tasked with coordinating weather information at TMC	Institutional – Level 2 Operational – Level 2 thru Level 5 Technical – Level 1 thru Level 2	**Pros:** No additional staffing, provides a focus, champion, and, go-to person. **Cons:** Becomes another task and additional responsibility among tasks for an individual that may result in limited effectiveness when competing responsibilities exist, relies on enthusiasm of a champion.
	Dedicated weather operations supervisor	Operational – Level 3 thru Level 5 Institutional – Level 3 Procedural – Level 3 thru Level 5	**Pros:** An ideal strategy to ensure appropriate integration methods are implemented to meet complex organizational and weather influence needs with continuing quality improvement. **Cons:** There needs to be sufficient weather-related demand for the services of a dedicated individual to justify the position.
Continuously available weather information	Internet provided, public access general forecasts, weather radar or satellite image	Operational – Level 1 Physical – Level 1	**Pros:** Utilizes availability of information accessible from numerous public web sites; low cost, low maintenance, low effort. **Cons:** Public forecasts are broad brush and general, and they have marginal value for planning and directing operations. Use of satellite and radar information requires extensive staff training to be interpreted relative to TMC operations.

Table 9. Weather Integration Concepts and Methods (continued).

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Continuously available weather information	General weather information, forecasts, and interpretation provided through Cable Channel or non-surface transportation specific subscription weather information vendor	Operational – Level 1 Physical – Level 1	**Pros:** Minimum cost, low maintenance, low effort, the interpretation of radar and satellite imagery is provided by on-air broadcast meteorologist. **Cons:** Not specific to operational needs and inadequate during events. The provider's focus may not be on the desired operational area or updated frequently enough. Subscription general weather information requires interpretation relative to the context of TMC operations; imagery is not interpreted.
	Contractor provided surface transportation weather forecasts targeted at the operational needs of the TMC agencies	Technical – Level 1 to Level 3 Operational – Level 1 to Level 2	**Pros:** Contractual and therefore can be customized to needs and designed to be available at a frequency and time appropriate to operations. **Cons:** Requires knowledgeable RFP development and contract management, e.g. dedicated weather operations supervisor.
	Field observers or probes providing scheduled weather / driving condition information from entire route system	Operational – Level 3 Procedural – Level 2	**Pros:** Low technical deployment possible. It meets multiple sourcing, analysis, and mitigation needs. It provides information for advisory, treatment, and control responses. It provides information, not just where ESS or CCTV are deployed, and continuous coverage, not just "bad" weather. **Cons:** Must be frequent enough to be valuable and systematic enough to provide information integrity. Requires significant institutional and procedural commitment and planning.
	Meteorology staff located within the TMC forecasting and interpreting weather information	Technical – Level 1 to Level 2 Physical – Level 3 to Level 5 Institutional – Level 3 Level 5	**Pros:** A relatively non-technical sourcing and analysis integration solution in TMC maintaining daily awareness of weather and forecasts generating awareness as required by TMC agencies. Also provides high operational benefits from physical integration, no requirements of traffic staff during periods of non-disruptive weather. **Cons:** Requires recognition of the value of this method relative to the higher costs to implement it.

Table 9. Weather Integration Concepts and Methods (continued).

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Automated thresholds or escalation notification	Extra services (Email, or page being offered to public by commercial general weather forecast organizations	Operational – Level 1	**Pros:** Low cost, low maintenance, low effort. **Cons:** Uncertain reliability and not specific to transportation needs. Limited choice in types of information available for distribution.
	TMC road weather system (RWIS / ALERT / FEWS) generated specific notifications (Email or page)	Technical – Level 1 Operational – Level 2 thru Level 5 Procedural – Level 2 thru Level 5	**Pros:** Is customizable, specific to TMC needs and is based on transportation system specific needs (e.g. fog, icing, flooding) **Cons:** Requires dedicated attention to on-going maintenance. May not cover all locations of concern in road network.
	Personally initiated and delivered notification through e-mail, page, and/or phone call from surface transportation weather information vendor	Technical – Level 0 thru Level 2 Institutional – Level 3 Operational – Level 2 thru Level 5 Procedural – Level 2 thru Level 5	**Pros:** A low tech and effective solution, very specific to needs. It is based on continuous weather observations by technical staff and allows the weather staff to focus on weather, transportation staff on the system, maintenance staff on mobility. **Cons:** Someone must always be available for the phone call. If the vendor is going to call one distribution point for dissemination it has to be procedurally clear as is the case when union rules govern off-time availability.
	Protocol driven, sequential activation of additional TMC functions, operational nodes, or satellite facilities	Procedural – Level 2 thru Level 5 Technical – Level 2 thru Level 5	**Pros:** Maximizes mobilization and effective, efficient use of resources during events. **Cons:** Requires high procedural and institutional effort and organization.
	Daily personal briefings and integrated interruptions by meteorology staff within the TMC	Operational - Level 2 thru Level 5 Procedural – Level 2 thru Level 5 Physical – Level 3 Technical – Level 1 thru Level 5	**Pros**: A relative non-technical integration solution in TMC meeting analysis and advisory needs of operational staff. **Cons:** Requires recognition of the value of this method relative to the higher costs to implement it, and sufficient demand to justify the costs.

Table 9. Weather Integration Concepts and Methods (continued).

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Seamless integration of multiple sources and subsystems	Geographic visualization of road conditions, snow plow positions and recent coverage, precipitation / wind / visibility	Technical – Level 2 thru Level 5 Institutional – Level 3	**Pros:** This provides easy mental integration and understanding, i.e. analysis for increased situational awareness by TMC staff. A high standard of staff meteorology training or expertise is not required, allowing them to focus on appropriate response to weather conditions. **Cons:** Requires expert design and thoughtful layering of information to provide a valuable and useful analysis tool.
	Vendor provided single source or system integration	Technical – Level 2 thru Level 5	**Pros:** Turn-key solution for hardware and software that connects and organizes all weather information resources desired by TMC associated agencies. **Cons:** Modification and improvement requires vendor participation. Unless site configurable in functionality, it could result in a “one size fits all” solution that is less than effective.
	TMC integrated weather information system developed and maintained by in-house staff	Technical – Level 2 thru Level 5	**Pros:** Connects and organizes all weather information resources desired by TMC associated agencies. It provides for flexibility, growth, streamlined improvement, and agency control, customized design optimizes effectiveness for a specific TMC. **Cons**: Requires specialized staff and may have high initial deployment costs.
	Optimized integration of weather information and transportation system information through software and visualization combining weather observations, road conditions, traffic flow	Technical – Level 4 thru Level 5	**Pros:** The whole is greater than the sum of the parts combining valuable traffic information as well as weather information that provides for better transportation system response than individual agencies operation independently to whether the weather is influencing the traffic. **Cons:** The methods and supporting research are not yet available.

Table 9. Weather Integration Concepts and Methods (continued).

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
TMC provides the operations center, administration and clearinghouse for weather information	Weather information is synthesized and delivered through seamless integration of information combined with seamless distribution	Technical - Level 2 thru Level 5 Operational – Level 3	**Pros:** Identifies and services both internal and external customers providing mechanism for institutional integration. **Cons:** Requires moderate level or greater of technical integration effort.
	House and maintain the systems that collect and distribute weather information (RWIS, ALERT, FEWS, 511) within the TMC.	Technical – Level 2 thru Level 5 Physical – Level 2 thru Level 5	**Pros:** The best available information is readily available at all times, and this can be achieved in a variety of ways in the TMC to aid with data management and interpretation. An economy of support and technical skills is realized. **Cons:** Requires weather information integration to be institutionally part of TMC.
	Source (meteorology or weather operations staff) of surface transportation weather forecasts utilized by TMC associated agencies is located within the TMC.	Operational – Level 3 thru Level 5 Physical – Level 3	**Pros:** TMC gains spill-over benefit functionally integrating weather information within its core responsibility. **Cons:** Requires recognition of the value of this method relative to the higher costs to implement it and sufficient demand for at least one of the TMC participating agencies.
	Co-location of the EOC	Operational – Level 3 Physical – Level 2 thru Level 5 Procedural – Level 3 Institutional – Level 3	**Pros:** Where disaster-like weather events are recurrent, the TMC gains operational integration efficiency by including the presence of EOC operations during those events. This succinctly integrates high impact / low frequency events with transportation system operation. **Cons:** Requires supportive institutional philosophy and leadership, and physical integration.
Community awareness between the TMC and weather communities	Focus group or informal gatherings of local professionals from the transportation management and weather communities	Physical – Level 1	**Pros:** Provides low impact mechanism for institutional integration at the local level. **Cons:** Requires the presence of local groups willing to take the extra time to form the local activities.

Table 9. Weather Integration Concepts and Methods (continued).

Concept	Method	Primary Integration Dimension and Level	Pros & Cons of Concept / Method
Community awareness between the TMC and weather communities	Joint national association meetings with exchange of operational methods and requirements	Physical – Level 2 Institutional – Level 3 thru Level 5	**Pros:** Provides professional development opportunities and a national emphasis for participation. **Cons:** Each community has different national associations with little reason for forming a joint meeting resulting in significant institutional indifference.
	Computer-based training materials or short (1-2 day) training courses highlighting each community's operations	Institutional – Level 3	**Pros:** Provides an effective focus effort to convey expectations and capabilities of each community. **Cons:** Requires supportive institutional leadership at the federal agency level to foster funding and developmental assistance for training materials.
Decision Support	Use quick-reference flip cards on operator's workstation.	Procedural – Level 2	**Pros:** A low cost, low technology, less experience requirement method ensuring consistent information analysis. **Cons:** Limited to recurring, highly similar events and actions not requiring complex operational integration.
	Source (meteorology or weather operations staff) of surface transportation weather forecasts used by associated agencies is located within the TMC.	Operational – Level 3 thru Level 5 Physical – Level 3	**Pros:** Expert / timely advice regardless of conditions that are changing or suspect weather forecast models. **Cons:** Requires recognition of the value of this method relative to the higher costs to implement it, and sufficient demand for at least one of the TMC participating agencies.
	Automated condition recognition and advisory or control strategy presented to operator for acceptance into ATMS	Operational - Level 3 thru Level 5 Technical - Level 3 thru Level 5 Procedural - Level 4	**Pros:** Improved operational efficiencies through faster analysis requiring less individual operator situational awareness, provides for supported human oversight in system. **Cons:** Research required to identify appropriate control strategies and optimal/most effective advisory messages, based on human factors research to determine which messages will lead to the most appropriate driver response/action.
	Response scenarios through software supply potential solutions with outcomes based on weather / traffic modeling	Technical – Level 3 thru Level 5 Procedural – Level 4 Institutional – Level 4	**Pros:** Provides experience and knowledge base beyond individual operators, allows what-if's and learning situations; tracks solution verification. **Cons:** Requires near real-time traffic / weather modeling not currently available.

In addition to the concepts and methods, Table 9 provides two other important characteristics for each method: primary integration dimension and level, and other comments that provide insight into whether or not this method would be appropriate for a particular TMC. Each of these characteristics is discussed in more detail below.

The *primary integration dimension and level* column refers to the five integration dimensions discussed in the Chapter 1 – operational, physical, technical, procedural, and institutional – and an integration level (0 to 5) as assessed by the study team. The results of a TMC conducting a self-assessment (refer to Recommendation #3 in Section 3.3.1) should identify what weather information integration is needed and which integration dimension enhancements will result in the greatest benefits. This column in the table identifies, for each method within a concept, the primary integration dimensions affected. Additionally, an assessment of the level of integration associated with each dimension is provided. This level (0 to 5) is a relative value that indicates the degree of integration achieved and the extent of effort required achieving that level of integration. A 0 to 3 scale was used during the baseline conditions analysis of each site visited, and it reflected the judgment of members of the study team regarding the levels of integration that could be used to understand the state of integration at each site on each dimension of integration, from no integration ("0") to the highest level observed ("3").

Table 10 provides the measurement scale 0 to 3 for each integration dimension used in the baseline report, but slightly revised from the measure definitions used during the baseline analysis to fully reflect the most current thinking of the study team and to be consistent with the concepts and methods in Table 9. The 0 to 5 scale builds on this original scale by adding two additional levels to provide for more advanced forms of integration and the evolution of potential future integration concepts and methods. It is proposed in Recommendation #4 (Section 3.3.1) that the integration levels 4 and 5 be researched further and defined in detail.

The last column in Table 9 provides the pros and cons of implementing each concept/method combination. Understanding some of the advantages and disadvantages of implementing each method is provided to assist TMC managers in determining the best configuration of concepts and methods that meets the unique needs of the region or state for which the TMC has responsibility.

An example of how Table 9 might be used by TMCs is provided in Section 3.2.4.

Table 10. Weather Information Integration Measurement Scale: Dimensions and Levels.

Level	Definition of Integration Level for Each Integration Dimension
Operational	
0	No weather information used.
1	Weather information is part of background within the TMC, sourcing is not coordinated; there are no analysis strategies.
2	Coordinated sourcing of weather information for limited or single analysis or mitigation.
3	TMC coordinates with co-located agencies in sourcing, analysis, and mitigation.
Physical	
0	All agencies or systems sourcing or analyzing weather information are outside of TMC.
1	TMC shares physical presence with other agencies using weather information for analysis or mitigation.
2	TMC houses and maintains primary weather information system.
3	TMC shares physical presence with primary weather information source and other information-using agencies.
Technical	
0	TMC uses public systems to source weather information.
1	Weather information source is multiple, individual display(s) of public and/or vendor systems.
2	Multi source weather information is combined in unified user interface for analysis.
3	Multi source weather information is combined in unified user interface for analysis and integrated for limited mitigation uses (advisory, control, or treatment)
Procedural	
0	No weather information sourcing, analysis, or mitigation strategies in place or used.
1	Informal, unwritten TMC weather information strategies.
2	Individual or select TMC agencies have weather information strategies.
3	TMC agencies physically and technically integrated coordinate weather information strategies
Institutional	
0	TMC staff is unfamiliar with roles and responsibilities of weather information use. No active management support for weather information strategies. No agreements are in place that encourage institutional integration.
1	TMC staff has general idea of weather-related roles and responsibilities of other agencies, or weather information use is limited to within individual agency or group.
2	TMC staff informally coordinates weather information use with other agencies, awareness through use of single strategy, concept, or method.
3	TMC weather information use includes data sharing and national format use, and formal agreements with other agencies. Management places a high value on integrated, collaborative working relations and decision-making. Agreements are in place that encourage integrated working relationships.

3.2.4 How to Use the Concepts and Methods

The following is a hypothetical example of how a TMC manager might use the concepts and methods in Table 9 to enhance the level of weather information integration.

A northern state TMC experiences winter weather that affects road conditions and is currently employing the following weather information integration concepts and methods to provide weather information to its transportation operations personnel:

- TMC Manager acts as the weather information coordinator.
- Cable channel weather information provided on TV in corner of operations floor.
- One DOT District receives detailed road weather forecasts from a contract surface transportation meteorologist (information provided directly to District; TMC does not receive it).
- Data from a limited number of ESS deployed statewide are integrated into one server and available on a terminal in the TMC.
- The limited weather information available in the TMC is used by traffic operations personnel (in the TMC) to provide advisories on DMS and 511/Internet web page. No control strategies, such as changing signal timing or adjusting variable speed limits are implemented to reflect current road weather conditions.
- Currently, winter road maintenance operations is dispatched and managed at the Districts.
- Maintenance managers obtain general and road weather information from several sources (not coordinated between Districts).

Using the measurement scale provided in Table 10, the TMC manager rates the center in terms of weather information integration as follows:

Operational	Physical	Technical	Procedural	Institutional
1	0	1	0	1

During a self-assessment, the TMC manager understands the needs of his operations personnel and the center's customers to more quickly and accurately address weather conditions affecting the roadways. A summary of their needs include:

- A person designated in the TMC to focus on road weather information and integration
- Traffic operations personnel and winter road maintenance dispatchers need to be more aware of pending weather conditions that may affect road conditions
  - Need more accurate, timely, and location-specific weather forecasts to support traffic operators and maintenance dispatchers decision processes
  - Need to have more timely alerts to potentially dangerous weather or weather that could significantly impact road conditions to more quickly respond
  - Need better approach to access ESS/RWIS information and alerts when particular thresholds are met

- More coordinated management and dispatch of maintenance operations
- TMC personnel need better education on how to use weather information in traffic and maintenance operations and what integration techniques and tools are available

Using information from Table 9 that provides integration approaches and methods potentially usable in TMCs, the TMC manager decides that implementation of the following concepts and methods are required to increase the level of integration in the example above:

- The TMC Manager assigns a senior technical staff member the responsibility of weather information coordinator.
- The new weather information coordinator arranges for selected TMC staff and management to participate in a FHWA-sponsored training course on weather information integration and techniques in TMCs.
- The TMC Manager works with state DOT management to collocate all maintenance dispatching and operations into the TMC.
- The Weather Information Coordinator expands the role of the contract surface transportation meteorologist to provide surface transportation weather forecasts statewide.
- Multiple sources of weather information, including ESS/RWIS data and meteorological observations and forecasts, are integrated and provided graphically on the TMC video wall.
- Software is developed to provide traffic and maintenance operators in the TMC with tailored alerts, based on specified thresholds being met, at their terminals.

These efforts are divided into manageable projects and funding is secured for the coming fiscal year. Partnerships are explored with related agencies that may benefit. Following a year of operation with these new integration techniques, the TMC Manager directs the Weather Information Coordinator to evaluate the new systems and procedures and make suggestions for changes and/or enhancements for the next fiscal year.

3.2.5 Potential Benefits

Benefits will vary depending on the conditions and level of integration at a TMC. This section lists some of the kinds of benefits that have been experienced by TMCs that have effectively implemented weather integration strategies. Although a comprehensive analysis of the benefit to cost of weather integration has yet to be done in any objective, systematic manner, many observed and anticipated benefits of weather integration are reflected in existing best practices at TMCs. Enhanced integration of weather information can result in the following kinds of benefits:

- Direct benefits through the quality and availability of advisory strategies, available transportation system control actions, and dispatch needs of operationally integrated agencies.

- Indirect benefits through improved TMC activity flow minimizing the change in effects from an inclement weather day to a clear weather day.
- More efficient winter road maintenance operations by providing information, including Intelligent Transportation Systems (ITS) and Advanced Transportation Management Systems (ATMS) generated traffic and road condition information, to support treatment strategies.
- Better prepared TMC operators to address adverse weather on the transportation system in terms of appropriate staffing and implementation of traffic advisories and control strategies.
- More timely and accurate information provided to the traveling public, thereby increasing customer satisfaction.
- A common focal point for TMC-related agencies enhancing institutional, procedural, and operational integration.
- Improved public safety through reduced incidents resulting from more effective application of traffic management strategies that incorporate weather information.

3.2.6 Potential Challenges

During the site visit data collection and subsequent discussions with TMC managers, several challenges to weather integration within the TMC were identified. As mentioned before, the approaches taken to implement this type of integration were specific to the needs of the region or state. Not surprisingly, the challenges were also specific to the needs of a particular TMC attempting to enhance their level of weather integration. The study team believes that many of these challenges may be faced by other TMCs when they begin to enhance their weather integration capabilities. The following potential challenges (and approaches to dealing with them) that were expressed by the TMCs are offered in support of future integration. It is hoped that by understanding some of the challenges that might be faced by a TMC interested in weather integration and how these challenges could be addressed, it would facilitate eventual implementation.

Lack of national-level TMC coordination. TMCs across the country view themselves as fitting into a blend of three core functions: information clearinghouse, operations center, and/or emergency manager. This reflects the mixture of agencies and intra-agency departments that is unique to each TMC. The unique approaches to operations and integration contained in each TMC are not easily shared with other TMCs that may be facing similar issues. There is no TMC clearinghouse association that regularly brings together this varied group to discuss common interests. Therefore, cross-pollination and opportunities for TMCs to learn from others' experiences and practices are very limited. If such a venue existed for TMCs to share ideas, it may facilitate addressing many of the challenges discussed in this report.

Recognizing opportunities for weather integration and building support to address them. In most TMCs weather integration is not a focus of the center, and many opportunities to enhance capabilities are not acted upon. Many of the other challenges discussed here also contribute to lost opportunities; however, a champion within the TMC, someone who is committed to improvement in operations through expanded weather (information and systems) integration, can provide the needed leadership to take advantage of the opportunities and overcome the challenges. This commitment can be the basis for building the institutional and technical support needed to identify and implement integration solutions. The surface transportation weather community may also be able to assist in identifying opportunities and suggesting possible beneficial solutions.

Lack of awareness of the use of weather information in traffic operations and integration opportunities. The use of weather information in DOT maintenance operations (primarily winter maintenance in northern states) is now widely accepted as critical to an efficient maintenance program. It has taken over fifteen years to achieve this level of awareness. The awareness of weather information use in traffic operations is just beginning. There is a need for aggressive and coordinated awareness building and training programs to facilitate acceptance in this area of transportation management.

The TMCs that successfully overcame this challenge did it by understanding how different weather conditions affected their transportation system and management approaches. They brought together the traffic operations staff and weather information community to investigate the system needs and potential solutions. The weather information community may have included National Weather Service (NWS) representatives, sensing equipment vendors, system developers/integrators, and surface transportation weather service providers. Together, they developed integration solutions that met their needs, many of which are represented in the concepts and methods documented in Table 9.

Access to traffic control strategies and devices. State DOT TMCs have limited access to electronically controllable traffic control devices such as traffic signals and lane use signals that can be used to respond to weather events, especially when the weather event suggests adjustments to such control devices to facilitate traffic demand. A stronger link between DOT TMCs that may have useful weather information and those agencies managing local traffic control devices could help to enhance their ability to respond to weather events.

Variations in the determinants of integration. Figure 1 identified various determinants of integration for a particular region or state including transportation context, exposure to events, institutional structure and climate, and access to resources. These determinants may vary significantly from one jurisdiction to another, which could drive the different solutions. Because of these different conditions, the challenge will be for FHWA to help guide the continued development of weather integration in TMCs. For instance, attempting to categorize the type and severity of weather events by geographical region has proven to be a significant challenge. Additionally, variation in the political orientation in each jurisdiction may impact the integration solutions, access to funding and the commitment to implementation.

Limited national experience with TMC weather information integration. Closely associated with the two challenges described above is the fact that there is very limited and disparate experience nationally to use as examples to illustrate the benefits of weather integration. The ten sites visited during this study represent the most advanced TMCs integrating weather and emergency information into their operations and should be used as examples for others interested in enhancing their capabilities. Because there is such limited experience and the TMCs that have pioneered the current state-of-the-practice have done so without the use of other examples, it is no wonder that the homegrown solutions are hard to apply elsewhere. It is believed that as more TMCs realize the benefits of weather integration that a more complete representation of best practices will emerge, expanding the experience base that can be shared with TMCs interested in enhancing their weather integration capabilities.

Understanding the benefits of weather integration versus the costs of implementation. The cost of weather integration was expressed as a challenge by almost all the TMCs contacted. TMCs have found it difficult to show justification for the allocation of scarce funds for weather integration. These costs may include the procurement of sensing equipment and computer hardware and software, maintenance of installed equipment, staff to coordinate the weather information integration activities, or contract services to provide weather forecasting. The primary challenge is to understand the benefits that would be realized by the implementation of the integration proposal. This challenge is compounded by the fact that a comprehensive analysis of the feasibility and benefit-to-cost of weather integration has yet to be performed in any objective, systematic manner. Section 3.2.5 above identifies some of the potential benefits that have been experienced by TMCs that have effectively implemented weather integration strategies. The successful TMCs investigated their respective potential benefits and built strong cases (not necessarily based on measurable cost savings benefits) to their management for enhanced integration. They followed this with evaluation activities to strengthen their cases as they implemented various integration approaches. Several TMCs also utilized the results of customer satisfaction surveys to support their weather information integration activities.

Need for the National ITS Architecture to better reflect the emerging use of surface transportation weather in transportation applications. Traffic Management Centers (TMCs) exist to integrate technologies, agencies, and information to improve the safety and efficiency of traffic and transit systems. The National ITS Architecture is an important tool to facilitate and organize ITS integration activities in a TMC. The National ITS Architecture is based on ITS user needs that are linked to a set of ITS user services. At present there is no "weather" user service within the National ITS Architecture, but it does describe how weather information can affect the various ITS user services. However, integration of weather information at a TMC goes beyond the present representation within the current version of the National ITS architecture. Several TMCs commented that the existing architecture incorrectly illustrates how weather information flows and is used in transportation management. TMCs have significantly tailored their operations, and hence their architectures, to reflect real-world, inter-agency applications of weather information integration. Much of this has resulted from the growth of more sophisticated capabilities that continue to be developed by surface transportation weather service providers. A recent study completed for the Intelligent Transportation Society of America, known as the *ITS America Weather Services Study*,[10] identified the need to improve the representation of weather and surface transportation weather information within the framework of the National ITS Architecture. The results of the present TMC weather integration study also find a need to more appropriately reflect the current and emerging role of weather within TMCs within the National ITS Architecture.

3.3 RECOMMENDATIONS

Nine recommendations are offered to assist the Federal Highway Administration and TMC administrators to enhance the level of weather information integration into TMC operations. These are divided into enhancements to the current practice (5 recommendations) and future supporting research (4 recommendations). Each recommendation identifies the proposed responsible group that is intended to be the implementer. Details of these recommendations follow.

3.3.1 Enhancements to Current Practices

Recommendations

Enhancements to Current Practices:

1. Create an institutional culture within the TMC that is aware of weather information and how it can be used to improve operations.
2. Provide awareness-building and training to TMC management regarding benefits of targeted/tailored weather information in TMC operations.
3. Conduct a TMC weather information use self-assessment and develop an integration plan.
4. Develop a set of guidelines to enhance TMC integration of weather information.
5. Improve communications between weather and transportation communities related to traffic operations.

Future Supporting Research:

6. Investigate potential future concepts and methods (e.g. decision support).
7. Develop a toolkit to assist in the integration of weather and traffic information sources.
8. Foster a focused road weather research program supporting TMCs.
9. Establish management strategies and rules of practice to support improved operations and enhanced weather integration.

The first five recommendations are focused specifically on enhancements to the current practice of TMC weather information integration. Each of the recommendations provides specific leadership actions either FHWA or TMC administrators can take to enhance the level of weather information integration with the goal of improving the overall operational effectiveness of the TMC.

Recommendation 1: Create an institutional culture within the TMC that is aware of weather information and how it can be used to improve operations

Scope: TMCs should establish a weather operations advisory committee or designate an individual as the weather information coordinator.

Leadership: Transportation Management Center Administrators/Managers

Expected Outcomes: The expected outcomes of enhanced weather information awareness and a TMC structure in support of increased integration include:

- Recognition of cross-institutional similarities, wider application of existing sources of weather information, and areas where combined resources can result in acquisition of higher value weather information such as specialized forecasts.
- Economy of scale in combining technical integration solutions for multiple agencies utilizing similar surface transportation weather information.
- Procedural homogeneity in integration that involve diverse response from various agencies to the same weather event.
- Visibility of TMC's value as a multi-agency integration mechanism.

Description/Approach: Integration of weather information requires an awareness of how it can benefit from the multitude of activities present within a TMC. For a TMC to successfully integrate weather information there must be a focal point (advisory committee or designated individual) to ensure weather information is taken into consideration for all relevant activities and ensure that available information is appropriate and meets the needs of the TMC and the organizations its integration represents. The complexity, severity, and frequency of weather / traffic events guide the extent of sophistication required to accomplish this goal.

The implementation of this recommendation can begin with the establishment of a weather information coordination committee representing all agencies connected with the TMC whose activities might be influenced by weather events affecting the transportation system. A higher level of sophistication would be illustrated by having an individual within the TMC operation or supervisory staff being designated as the weather information coordinator. At the highest level of sophistication a statewide or regional weather operations supervisor is a member of the TMC staff who oversees the integration of weather will all aspects of the transportation system, including traffic, maintenance and construction. This person manages the deployment, maintenance, and operation of any roadside or transportation system environmental sensor stations; ensuring seamless integration and delivery of weather information to all transportation system customers both internal and external.

Recommendation 2: Provide awareness-building and training for TMC management regarding the benefits of targeted/tailored weather information in TMC operations

Scope: TMC administrators often do not fully understand the difference between generic weather products and those targeted/tailored to the surface transportation decision maker. Additionally, they do not understand how integrated weather information (tailored) can support TMC operational effectiveness. It is recommended that outreach, education materials and training be provided to increase the awareness of targeted/tailored weather information sources, tools, and integration of best practices/techniques. Through increased awareness of how integrated weather information can benefit TMC operations, there is the potential to have an effect on all the dimensions of integration (operational, physical, technical, procedural, and institutional).

Leadership: Federal Highway Administration, Road Weather Management Program

Expected Outcomes: The expected outcome of implementing this recommendation is an increased awareness of TMC management to the benefits of integrated weather information to support more effective TMC operations. This awareness would hopefully encourage specific ideas of how to implement integrated weather information concepts and methods tailored to the needs of the TMC.

Description/Approach: The education being recommended here needs to include all aspects and potential benefits of implementing the weather information integration concepts and methods described in Table 9. This would include integrating various sources of road weather information for efficient management decisions as well as the integration of road weather information with traffic operation information.

It is recommended that the Road Weather Management Program develop a comprehensive plan to train both TMC operators and the road weather information community regarding the benefits of integration. This education program should include an effort to increase awareness, provide computer-based training materials, and develop and present a National Highway Institute (NHI) course. The first step will be to increase awareness with a focused package advocating for road weather and TMC information integration. This could include a road show and/or DVD to be presented by Road Weather Management Program staff at TMCs that would illustrate the benefits and best practices throughout the country. For those TMCs interested in continuing their learning, the computer-based training would go into more detail on specific integration methods and potential implementation approaches. The computer-based training would be a prerequisite for enrollment in the NHI course that would be tailored to a region's or state's needs addressing how to integrate road weather information and traffic operation information in that specific situation. At the conclusion of the NHI course (and the education program) the TMC operators/management and the road weather community would better understand the needs of each discipline and the available information, approaches and tools to integrate road weather information in TMC decisions.

Recommendation 3: Conduct a TMC weather information use self-assessment program or process and develop an integration plan

Scope: TMCs should conduct a self-assessment to help identify the most effective integration solutions and guide their deployment. This will result in a plan to better integrate weather information into TMC operations. Since the self-assessment will evaluate all aspects of TMC operation and its use of weather information and develop an integration plan, this recommendation would affect all five integration dimensions (operational, physical, technical, procedural, and institutional).

Leadership: Transportation Management Center Administrators/Managers and key staff

Expected Outcomes: The expected outcomes of conducting a self-assessment include:

- Clear understanding of the weather situations that can affect traffic and transportation management in the region for which the TMC is responsible.
- Clear understanding of the related weather information needs of the TMC.
- Clear understanding of the weather information and weather integration tools available to address the needs.
- Identified appropriate weather information integration solutions that match the TMC needs for weather information.
- Reviewed/revised regional ITS architecture and concept of operations.
- A plan to integrate weather information into TMC operations.

Description/Approach: Regardless of what weather information integration level a TMC is at currently, if they are interested in enhancements to that integration it is recommended they conduct (or update if one already exists) a weather information use self-assessment and develop an integration plan. The inputs (bubbles) and steps (boxes) to achieve such a self-assessment are shown below in Figure 9.

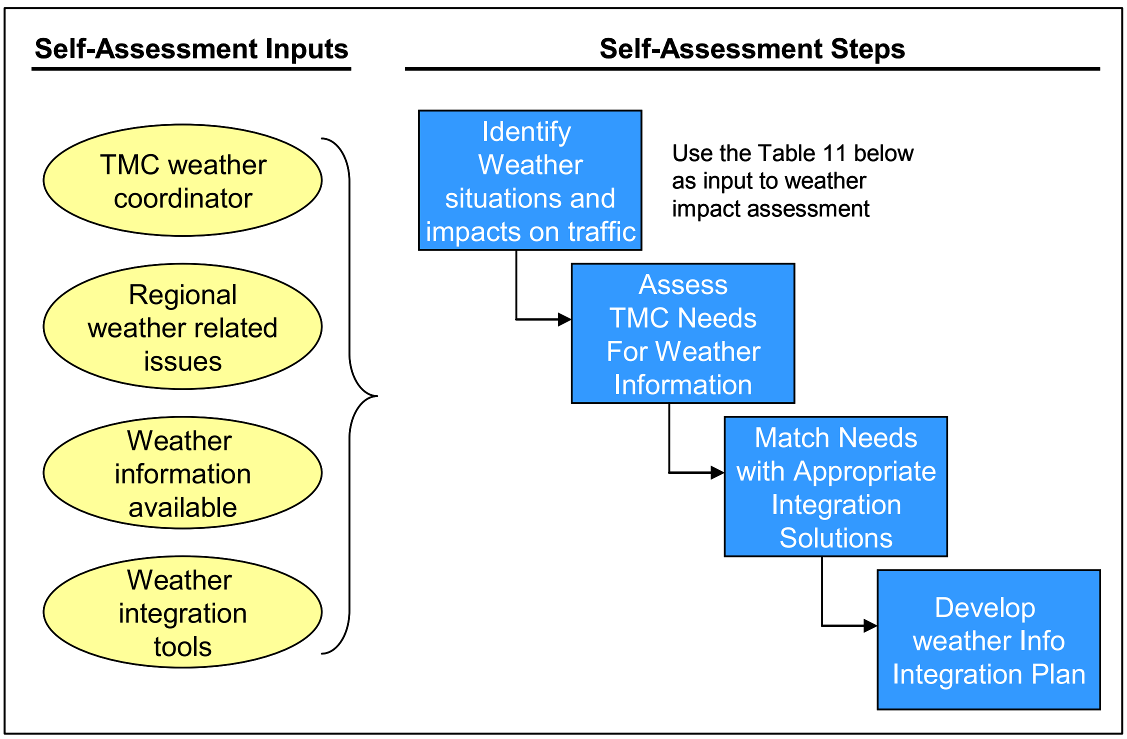

Figure 9. Recommended TMC Self-Assessment Process.

The self-assessment process begins with having a TMC weather coordinator (see Recommendation #1 above), and knowing the regional weather-related issues, weather information available, and potential weather integration best practices. The TMC weather coordination may want to elicit the assistance of the local, and perhaps national, weather community to work closely with the traffic operations personnel during this process. The first step is to identify the type of weather situations (and frequency) and their impacts on the transportation system managed by the TMC.

Table 11 provides a sample matrix that could be used to categorize the weather situations and the resulting impacts. The next step is to assess the needs for weather information.

Table 11. Sample Matrix to Categorize Weather Situations and Resulting Impacts.

Weather Event	Occurrences per year	Potential Impacts					
		Congestion	Transit Delays	Accidents	Dangerous Conditions	Road Closures	Staffing Adjustments
Rain							
Flooding							
Strong Winds							
Snow							
Blizzard							
Ice							
Hurricane							
Tornado							
(add other items as necessary)							

Table 11 offers a structured approach to answering the question, "What weather information does the TMC need to make better transportation management decisions to lessen the impacts in the future?" Next, it is necessary to match the weather information needs with appropriate integration solutions. The final step is to develop a weather information integration plan that meets the needs of the TMC. This plan should include the integration solutions identified in the self-assessment process and a deployment schedule for each solution. Costs should be estimated and used for budgetary purposes. Implementation of the plan should begin as soon as funds are available.

It is not the intent of this report to identify the weather information integration solutions specific to each TMC. One of the key findings of the Baseline Report was that each TMC is unique and the solutions need to be tailored to the needs of the area. However, there are many core integration concepts, and corresponding methods, that have been developed and are identified in Section 3.2.3 (Table 9) that can be utilized to assist TMCs in matching potential solutions with their needs. For instance, perhaps a TMC has general weather information available via a cable channel on a monitor on the operations floor, but that information is not getting to the TMC operators in a timely fashion, and the information is too general to be useful to make critical management decisions. Through the self-assessment process, this TMC may have discovered that they need more detailed weather information available to the operators continuously. In this case, a vendor-developed detailed weather "nowcasts" (short-range forecasts) and longer-range forecasts can be provided to the operators on their computer screens as often as they deem necessary or when a particular weather threshold is meant. There are too many of these possible scenarios and potential integration solutions to be able to discuss them all here. Using Table 9, and the outcomes from this process, the TMCs can develop the most appropriate weather information integration solutions that meet their needs.

The self-assessment process is likely to identify potential enhancements to information integration within the TMC, and it is inevitable that the TMC concept of operations and regional ITS architecture will require revision. The Region's ITS architecture provides a useful framework for applying the needs assessment to all dimensions of weather information integration within the TMC and between associated agencies and mapping an implementation strategy. Though regional ITS architectures represent information flow primarily as it relates to technical integration, they contain the majority of systems, subsystems and physical entities present at a TMC.

It is recommended that the regional ITS architecture be reviewed during the self-assessment process following the identification of needs and before integration concepts and methods are selected for implementation. This review should identify existing data flows of both weather information and traffic data. The review should support the most appropriate new information integration implementation approaches that are consistent with current operations. Additionally, the concept of weather-responsive traffic operations has expanded and matured since many of the regional ITS architectures were prepared. New philosophies and new, restructured market packages incorporating surface transportation weather information are now available and relevant. This exercise can also update the regional ITS architecture to be consistent with the current National Architecture. Revisions should be identified and implemented in the regional ITS architecture to reflect the proposed road weather and traffic information integration concepts and methods. These revisions should include technical, physical, and institutional interconnections of equipment, data, and staff.

Recommendation 4: Develop a set of guidelines to enhance TMC integration of weather information

Scope: A set of guidelines should be developed to provide a roadmap of potential integration concepts and methods that could be implemented by TMCs interested in weather information integration enhancements. These guidelines should address all five dimensions of integration (operational, physical, technical, procedural, and institutional). The results of this effort can be used to support Recommendation #3, conducting a self-assessment and developing a plan to enhance integration.

Leadership: Federal Highway Administration

Expected Outcomes: The expected outcome of implementing this recommendation is a roadmap of possible integration concepts and related methods, for each integration dimension that could be applied at a TMC to enhance weather information use in transportation management decision-making.

Description/Approach: Guidelines are needed to assist TMCs that desire to enhance their level of integration with more advanced concepts and methods. Additional data will need to be gathered and research conducted in order to develop these guidelines.

It is recommended that FHWA begin immediately to develop these guidelines. The guidelines will need to address all types of TMCs regardless of their current (and future desired) level of integration. For instance, a TMC may be just beginning the process of weather information integration and wish to increase their capabilities to enhance their operation. In another situation, a TMC may already be demonstrating current state-of-the-practice weather information integration and desire to implement new state-of-the-art integration solutions. These and many other possible scenarios would need to be addressed by these guidelines.

The information presented in the Baseline Report (Appendix A) could be used as a starting point. Specifically the weather integration measurement scale defines integration levels from 0 to 3 for each integration dimension (Table 10, Section 3.2.3). This scale of weather information usage levels and their definitions could be used by TMCs to determine their current integration level. The TMC self-assessment (Recommendation #3) would identify the needs to be met through more advanced levels of weather information integration. Hypothetical integration levels 4 and 5 would need to be defined during this activity; however, the potential concepts and methods identified in Section 3.2.3 could be used to assist in that exercise.

Each dimension of integration will need to be addressed as well. The resulting guidelines can be displayed as a roadmap, in matrix form, allowing a TMC to quickly and easily identify concepts and methods that would meet their needs and desires for an enhanced level of weather information integration. An example of such a roadmap matrix is shown in Figure 10 below.

Using the weather integration measurement scale and the state-of-the-practice concepts and methods (refer to Section 3.2.3), a TMC could determine their current level of integration and the higher level of integration they wish to attain. As mentioned above, levels 4 and 5 would be defined as part of the effort under this recommendation. As in Recommendation #3 (self-assessment), there are several possible scenarios and solutions for any given TMC situation and integration dimension.

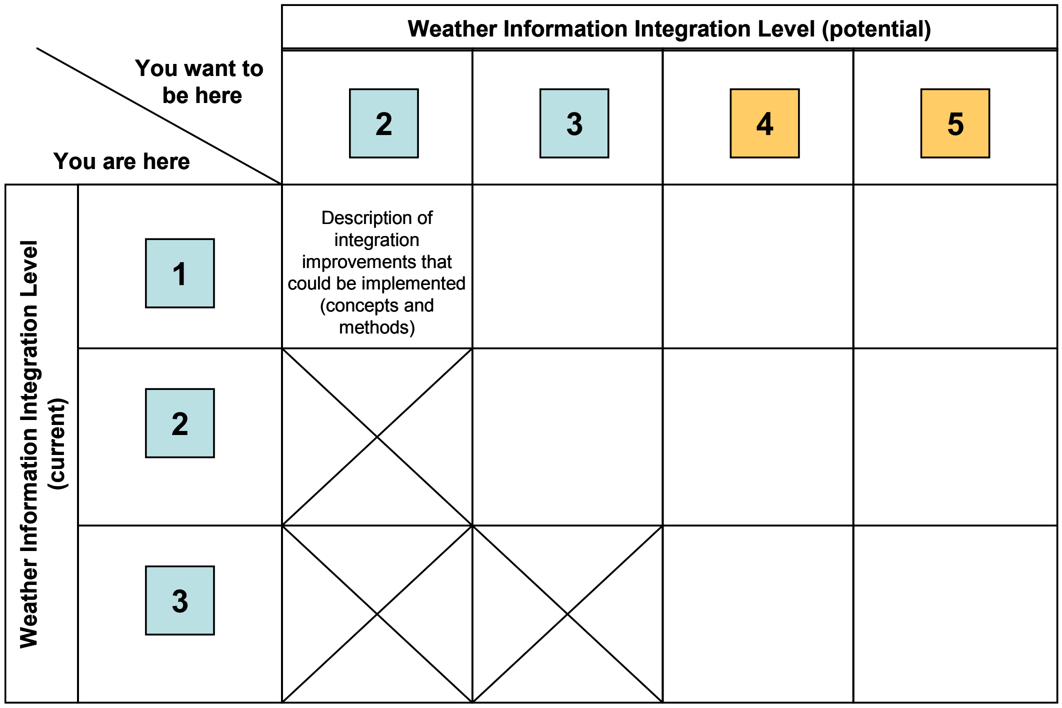

Figure 10. Weather Information Integration Guidelines Sample Matrix.

<u>Recommendation 5</u>: Improve communications between weather and transportation communities involved in traffic operations

Scope: The operation of TMCs involves vast amounts of information coordinated through physical and technical integration between entities within and peripheral to the TMC. Maintaining clear communications during these interactions results in efficient operations. Central to this effectiveness is an understanding of the expectations and requirements for information by personnel involved in the routine operations. Similarly, for effective weather integration within TMC operations it is important to establish a clear understanding of expectations and requirements involving weather information. However, knowledge of the capabilities and opportunities available from the weather community to the transportation community, including TMC operations, is limited. Conversely, the weather community is largely unaware of TMC operations and has a lack of understanding of the operational decision-making processes involved and how weather can best be provided to support the decision-making process. This lack of knowledge of the respective professional communities results in a lack of communications and possible miscommunications between these communities, as well as reduced effectiveness of traffic operations management prior to and during weather events.

Leadership: Individual TMCs, Federal Highway Administration, ITS America, American Meteorological Society, Transportation Research Board, Commercial Weather Service Providers, Academia

Expected Outcomes: It is expected that improved communications between weather and transportation, specifically traffic operations, communities will result to facilitate increased awareness of roles, responsibilities, expectations and limitations of capabilities within each community. This will also result in more effective institutional integration between the weather and transportation communities that will promote improvements in physical and technical weather integration.

Description/Approach: Improved communications can be accomplished by establishing forums and meetings where issues involving each community as it relates to the other can be addressed. The outcomes of these exchanges should provide heightened awareness of the interactions needed between weather and traffic operations, improved understanding of capabilities and limitations found within each community at present, and development of improved integration of weather within TMC operations for all dimensions of integration. By supporting the value of this kind of communications improvements, management leadership in institutional integration creates more effective traffic operations and benefits to the traveling public.

One such area crucial to address is improving the understanding of the needs of the TMC community and the capabilities of the weather service provider community. A particular area needing special attention is the improvement in understanding by the transportation community of the various products available from the weather service provider community. Communicating the differences between the structure, content, and accuracy of generic weather information from that of tailored surface transportation weather service products is crucial in advancing the level of sophistication in weather information usage by TMCs. Further, promoting an understanding of forecast accuracy, methods of monitoring forecast and weather data accuracy will improve the communications between the weather and transportation communities.

The meetings to improve communications should extend from the grassroots to the national level. Grassroots meetings can be as simple as local professional gatherings where discussions can be informally held. These informal gatherings could be fostered by exchanging guest speakers at meetings or hosting joint local meetings such that professionals become acquainted. The outcome of these meetings will provide local stimulation of ideas and promote collegial relationships and mutual trust on which to build a network of local associations between members of the weather and traffic operations communities. Examples of such meetings are presentations by TMC personnel at local American Meteorological Society Chapter meetings, meetings hosted at local TMCs with participation by the weather community, or presentations by weather personnel at state DOT or university sponsored meetings to discuss ITS issues involving traffic operations.

At a broader regional or national level, meetings or forums should be held where a larger audience participates to present more formal papers and exchange ideas during panel discussions. National transportation conferences, such as ITS America, should convene sessions devoted to fostering information exchange between the weather community and the traffic operations community. Such meetings have existed in the past primarily between the weather and transportation maintenance communities and have provided for improved awareness between these groups. In addition, the ITS America Weather Information Applications Special Interest Group should encourage a broader participation by traffic operations at future meetings. Similarly, the American Meteorological Society's Committee on ITS and Surface Transportation should be called upon to expand its membership to include representatives from the traffic operations sector. Finally, federal agencies such as the Federal Highway Administration or the Office of the Federal Coordination for Meteorology should be called upon to continue fostering greater interaction between the weather and traffic operations communities through national meetings under their direction. National workshops that bring together the broader weather and transportation communities, such as conducted at the University of North Dakota in August 2004 (http://stwrc.rwic.und.edu/workshop), should be encouraged and supported through these federal agencies.

3.3.2 Future Supporting Research

The current state-of-the-practice provides a point of reference useful for TMCs pursuing weather integration. However, to move beyond the current state-of-the-practice will require an expanded vision, enhanced awareness of integration opportunities, and further investment in the development of new methods and approaches in weather integration. Potential future methods may refine those found with existing concepts while others will likely be associated with new concepts.

Recommendation 6: Investigate potential future concepts and methods

Scope: Current concepts and methods may be insufficient to support more progressive levels of weather integration. Investigation of more appropriate concepts and efficient and effective methods to implement these concepts should be pursued as part of an on-going process to better utilize weather information within TMC operations.

Leadership: Federal Highway Administration, university research programs

Expected Outcomes: Continued growth of weather integration within TMCs that promotes improved benefit to cost.

Description/Approach: Examples of existing concepts that will benefit from research to enhance and expand their methods are "Seamless integration of multiple sources and subsystems" and "Decision support." The higher-level method of integration optimization between weather information and traffic information involves the use of sophisticated computer-based processes to effectively merge data and information systems to produce high impact solutions for traffic managers. Present software packages generally lack the capability to effectively merge weather information into a framework that specifically supports the needs and requirements of TMC operators. On top of this deficiency is the further lack of software systems that can combine traffic and weather information in a complimentary and synergistic manner that reduces the need for TMC operators to perform mental integration processes. Research on this optimal integration must involve studies that consider the routine and exceptional challenges involving weather encountered within a TMC. One additional significant element of this research must be a better understanding of the role human factors plays in the incorporation of weather information in TMC operation. It is important to perform analyses of human factors within the TMC operator work environment. The results of these analyses must then be included within the design of more ergonomic graphical display systems that minimize extraneous data and information and maximize weather integration and utilization with traffic information. The recommended human factors research would include the following elements:

- A review of workstation information currently used by TMC operators and weather information that will need to be integrated into these workstations, with a focus on how to seamlessly incorporate the weather information without adversely affecting the current information flow and operator tasks.
- Conduct a task and workload analysis, with a focus on understanding current operator tasks and the implications of adding potential additional tasks associated with weather management requirements on TMC operational performance.
- Assess how information is represented currently, including the use of symbols and ways information is represented to the operator, with a focus on incorporating weather information and symbols and icons in a similar way and format to reduce confusion and increase understanding and utility of the information flows.

As this optimal structuring and display of weather and traffic information becomes available, this information serves as a valuable resource for the expansion of decision support systems. The human factor research described above will be crucial to better define the operational processes involved in TMC operator activities. Expanding this research to include knowledge engineering of TMC operations will identify the decision chains associated with traffic management and the relationship of these decision chains to the data and information involved in making traditional operations decisions and the implications of adding weather information into the decision chain. From this the capability of building within a decision support system the recommendations of appropriate management strategies can be achieved. This process of combining knowledge engineering with heterogeneous data sources to provide management recommendations presently comprises the major effort associated with the Maintenance Decision Support System (MDSS) research and development being conducted by the FHWA and state DOTs. Utilization of lessons learned and technology developed within MDSS should prove valuable to the proposed TMC decision support system research.

The next step beyond decision support systems is the automation of certain aspects of TMC operations. While the automation of such operations represents a far-looking vision for TMC operations, it is important to begin the research to better understand and identify those processes and actions that are amenable to automation. The identification of low-level tasks and tedious actions currently performed by TMC operators represent the first opportunities to be explored. As autonomous actions become better developed, the TMC operator’s role will become more efficient and effective, and additional development can and should be explored.

Recommendation 7: Develop a toolkit to assist in the integration of weather and traffic information sources.

Scope: Existing software and hardware tools available to support the integration of weather and traffic information should be identified and promoted for use in fostering improved integration activities. This should include a review of current tools being used and the development of an appropriate framework for support access to these tools and their integration within TMCs.

Leadership: Federal Highway Administration

Expected Outcomes: This toolkit would provide a community collection of hardware and software solutions that can expedite weather and traffic information integration and serve as a foundation set of tools for application developers. Having such a toolkit as an open source will promote the adoption and further development of integration from within the development community.

Description/Approach: The resulting desired data structures of weather and traffic information integration will most likely be common across most TMCs. However, the originating data may vary considerably in format and general content between TMCs. The hardware and software actions required to complete this integration will depend upon having tools to support the acquisition and management of these data and information sources. As TMCs become more sophisticated in their weather integration activities, the software and hardware resources they use should be identified and cataloged for possible incorporation by other TMCs.

Recommendation 8: Foster a focused road weather research program supporting TMCs

Scope: The future growth of weather integration and utilization within TMC operations will depend not only on the willingness of the TMC personnel to adopt the integration paradigm but also the presence of solutions to existing challenges involving weather conditions. The development of a focused surface transportation weather research program will foster opportunities and a willingness of the research community to address these problems and to transfer the resulting technology to TMCs. This effort should place an emphasis on supporting the recommendations of the National Academies of Science Board on Atmospheric Sciences and Climate[11] calling for a national road weather research program.

Leadership: Federal Highway Administration

Expected Outcomes: It is expected that the pace of new solutions to existing TMC weather and traffic issues will be addressed through expanded research activities. This will result in improved operational efficiencies during adverse weather conditions and promote a safer transportation infrastructure.

Description/Approach: Problems associated with weather-induced congestion and the impacts on travel times are among the numerous problems that continue to challenge metropolitan areas. While changing the weather is not a viable option, understanding in advance the genesis and evolution of the impending weather impacts can be addressed better. This includes developing improved surface transportation weather prediction methods that leverage not only advances in the broader science of numerical weather prediction, but addresses fine-scale weather prediction challenges specific to surface transportation. Further, the challenges at present cut across the boundaries of weather and transportation. Present traffic flow models provide very limited inclusion of the vast amount of weather information that currently exists. Only through a vigorous interdisciplinary research and development program will problems such as this be addressed and resolved. To gain maximum benefit these expanded research opportunities must include the entire research infrastructure spanning from federal to university research laboratories within both the weather and transportation communities. The funding for this research effort must also be sustained over many years so as to permit the growth of the surface transportation weather research infrastructure as recommended recently by the National Academy of Sciences.[11]

Recommendation 9: Establish management strategies and rules of practice to support improved operations and enhanced weather integration

Scope: A goal of any research outcome should be the establishment of management strategies and rules of practice to support improved TMC operations. These become transferable standard operations actions that permit a measure of uniformity in operations across TMCs.

Leadership: TMCs, Federal Highway Administration

Expected Outcomes: It is expected that this effort will provide a pathway for all TMCs to achieve improved weather integration.

Description/Approach: The present use of management strategies rely heavily upon past technologies that fail to incorporate the benefits of improved road weather information. Through research that incorporates emerging surface transportation weather research findings along with advances in other areas of information technology, remote sensing, and decision science, the opportunity exists to create a new generation of management strategies that provide for improved safety, mobility and productivity. Technological advances are presently being made in such areas as winter road maintenance and traveler information through better incorporation of weather information for treatment and advisory strategies. However, more can be done in these areas along with improved weather utilization for control strategies. Regarding the latter, much can be done to improve the use of weather for controls strategies such as speed management, and evacuation and access controls. Through research these areas will be further advanced and brought to a new level of management strategies. As this research progresses and is validated through adoption and diffusion of the practices, the resulting changes in rules of practice will lead to improved TMC operations.

Research funds should be identified and allocated to permit the research and operations communities to codify those practices that provide a clear, effective and demonstrable management strategy that improves TMC operations through enhanced integration. These research studies should be used to identify common methods that are crosscutting across geographical and demographic scales and provide a constant measurement of the present best practices and their evolution. As weather and traffic integration evolves, such regular baseline investigations of the next level of best practices, conducted at intervals of no greater than every five years, will continually provide a pathway for all TMCs to the achievement of improved weather integration.

[9] Federal Highway Administration. 2003. *Weather-Responsive Traffic Management: Concept of Operations.* Draft report prepared by Cambridge Systematics, Inc. (January 10).

[10] Meridian Environmental Technology, Inc. 2004. *Weather Information in the National ITS Architecture Version 5.0.* (August). Pp. 58.

[11] National Research Council of the National Academies, Committee on Weather Research for Surface Transportation: The Roadway Environment. 2004. Chapter 5 in *Where the Weather Meets the Road: A Research Agenda for Improving Road Weather Services.* Washington, D.C.: The National Academies Press.

4. CONCLUSIONS

Transportation Management Centers are established across the country to integrate data, information and systems in support of day-to-day highway and transit operations. This study of weather and emergency information and systems integration in TMCs is part of a larger Federal Highway Administration program to better understand and support the safety and performance of our nation's transportation systems. In this study the focus is on operational performance when the systems are affected by weather or emergency conditions. The report explores how TMCs have implemented various concepts and methods of integration, describes the best practices observed during a series of TMC site visits, discusses the challenges and benefits of integration, and offers recommendations for how FHWA and the TMCs can enhance integration in the future.

Integration is understood to occur in several ways, including blended sources of information and data to support decision-making, joint consideration of weather and emergency information with traffic information and data, and the use of weather and emergency information and data with transportation-relevant information from a variety of linked agencies, including transportation (operations and maintenance), police, fire, and other emergency services. While this study examined some of the most advanced and integrated TMCs, the majority of TMCs operating today have either not begun to integrate weather and emergency information and systems into their operations or they have made relatively little progress towards integration. The many combinations of current integration concepts and methods presented in this study offer pathways for TMCs to advance their integration to meet the particular needs of their situation. However, more substantial improvements in integration can be achieved through the evolution of new concepts and methods that will require significant research and development investments. This report recommends that TMCs undertake a careful self-assessment process and prepare an integration plan to guide the selection and implementation of any of these integration strategies. Future research will need to be conducted to develop comprehensive guidelines, grounded in this initial study, for TMCs to follow.

Each part of the country presents a unique set of challenges to effective TMC integration based on climate, geography, politics, and transportation systems and resources. Depending on the concepts and methods of integration pursued by a TMC, the time and effort required will vary. The ability of TMCs to successfully compete for the limited available funds to support a more integrated approach to operations requires leadership, a supportive institutional environment, and the political will to invest in procedures to accomplish what are perceived to be unclear benefits and, in the case of emergencies, to address infrequent risks. Objective benefit-cost analyses of integration strategies are an important need.

Many observed and anticipated benefits of weather and emergency integration are reflected in existing best practices at TMCs. Although a comprehensive analysis of the benefit to cost of weather integration has yet to be done in any objective, systematic manner, it is apparent that integration is providing substantial value to current TMC operations. Observed benefits include the following:

- Better targeted, more timely, and higher quality content for traffic advisories and information provided both to the traveling public and to field operational staff.

- Coordinated transportation system control actions across integrated agencies.
- More consistent management of transportation operations under both normal and abnormal conditions.
- Enhanced TMC ability to anticipate weather and emergency conditions and to take appropriate mitigation actions before experiencing adverse system impacts, including staffing adjustments and implementation of traffic advisories and control strategies.
- Improved public safety and throughput due to a reduction in traffic incidents resulting from more effective application of traffic management strategies that incorporate weather and emergency information.

TMCs face a variety of challenges to achieving a successful and beneficial level of integration of weather and emergency information and systems. While many of these are related to the unique set of conditions faced at each TMC location, there are several broader challenges that are generally applicable to TMCs. The ability to promote the value of integration and to realize successful implementation of the kinds of integration concepts and methods described in this report will in part depend on making real progress towards resolving these issues and challenges.

- There is currently a low level of awareness within many TMC traffic operations of the opportunities and approaches available for better integration of weather and emergency information and systems to benefit operational performance. The prevailing perspective is that there are few if any actions a TMC can take outside of information derived from observations of on-going traffic performance. In addition, there is only limited national experience to date with integration of weather and emergency information and systems in TMCs. The importance of identifying champions who are committed and willing to promote integration cannot be overstated.
- There are few cross-agency integration guidelines or standards and no national-level TMC-focused stakeholder groups or clearinghouse to provide support and guidance regarding how integration can benefit and be applied to transportation operations. Related to this is a lack of organizational mechanisms in place to facilitate communications and sharing of ideas among TMCs, weather service providers, emergency managers, and others representing agencies that are a candidate for integration with TMCs but that currently operate quite independently.
- TMCs recognize that costs constitute one of their big challenges to accomplishing integration. While some concepts and methods of integration are less financially burdensome than others, it is difficult to generate funding support. In some cases the expected payback for investments in integration may take several years to realize.

This study has examined the best examples of TMC integration and described the underlying concepts and methods of integration that are being employed to enhance transportation operations. The practice of weather and emergency integration in TMCs is in its infancy, but the best practices illustrated in selected TMCs across the country offer examples of the long-term value of an integrated approach to transportation operations that other TMCs can emulate. It is hoped that the lessons learned in this study can help inspire and guide widespread efforts to achieve the benefits of integration in more TMCs in the future.

APPENDIX A

Baseline Conditions Report
May 20, 2005

The Baseline Conditions Report was the first of two reports completed under this study of integration. It provides the background and context for the Final Report and offers a wealth of data collected from TMCs that are implementing integration strategies across the country. While key information from the Baseline Conditions Report is replicated in this Final Report, the detailed results of the site screening interviews and the site visit reports are provided in this earlier document only. These detailed data and findings are expected to be of interest to researchers and practitioners who would like to know more about how individual TMCs are dealing with the integration of weather and emergency elements in their daily operations.

A copy of the Baseline Conditions Report may be obtained at no cost by submitting an e-mail request from the Federal Highway Administration at: Weatherfeedback@fhwa.dot.gov.

GLOSSARY OF TERMS

Term	Definition
ALERT	Automated Local Event Reporting in Real Time
ATIS	Advanced Traffic Information System
ATMS	Advanced Traffic Management System
CCTV	Closed Circuit Television
CEC	Combined Emergency Center
Clarus	The Nationwide Surface Transportation Weather Observing and Forecasting System (*Clarus* is Latin for "clear")
DHS	Department of Homeland Security
DMS	Dynamic Message Sign
DOT	Department of Transportation
EMS	Emergency Medical Services
EOC	Emergency Operations Center
ESS	Environmental Sensor Station
FEMA	Federal Emergency Management Agency
FEWS	Flood Emergency Warning System
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
ICS	Incident Command System
IMT	Incident Management Team
ITS	Intelligent Transportation Systems
MDSS	Maintenance Decision Support System
MPEG	Moving Picture Experts Group
NHI	National Highway Institute
NIMS	National Incident Management System
NOAA	National Oceanic and Atmospheric Administration
NWOS	National Weather Observation System
NWS	National Weather Service
RECC	Regional Emergency Communication Center
RTMC	Regional Transportation Management Center
RWIS	Road Weather Information System
SQL	Structured Query Language
TEOC	Transportation Emergency Operations Center
TMC	Transportation Management Center
TOC	Transportation Operations Center; Traffic Operations Center
U.S. DOT	U.S. Department of Transportation
VMS	Variable Message Sign
WIST	Weather Information for Surface Transportation
XML	Extensible Markup Language

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The involvement of representatives of numerous State DOTs and TMCs across the country was invaluable. This project could not have been undertaken without the support of these officials who participated in 38 lengthy site screening calls and met with team members during 10 TMC site visits. In addition, representatives of four of these TMCs attended a workshop held in Washington, DC. The TMCs visited were among the best integrated facilities in the country, and their staff contributed significant time and effort in support of this project. In addition to the TMC operators who participated in the workshop, representatives of FHWA, NOAA, and Mitretek also attended. All added significantly to a more comprehensive understanding of the role of integration of weather and emergency information and services in TMC operations.

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