CONDITION RESPONSIVE TRUCK ROLLOVER WARNING SYSTEMS:
ALTERNATIVE SYSTEM DESIGNS

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INTRODUCTION
Truck rollover is a serious highway safety problem, with consequences that make the occurrences important despite their relative infrequency. Truck accidents on urban freeways occur more frequently at interchange off-ramps that at any other location, accounting for about 5% of fatal truck accidents, according to accident statistics summarized in a study \(^1\) performed by Bellomo-McGee, Inc., for FHWA. Severe traffic disruption often results from truck rollover, and the severity of incidents can be sorely multiplied by the type of cargo the truck is hauling. Some hazardous cargos have the potential to cause true disaster if they are spilled as a result of truck rollover. Because of the severity of consequences of truck rollover accidents, it is important to seek ways to avoid such accidents. In the near-term future, the most likely means to prevent such rollover accidents is a condition responsive system that can warn truck drivers of impending rollover in time for them to take corrective actions.

SYSTEM REQUIREMENTS
In concept, a condition responsive truck rollover warning system would perform three primary functions, collection of data about vehicle and highway, determination of rollover risk, and operation of a device to warn the driver about the risk. These principal functions and their component subfunctions are described in more detail in the following paragraphs.

It is possible to design warning systems that are entirely infrastructure-based, or entirely vehicle-based. In addition, it is conceivable to design an integrated system that uses both infrastructure

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\(^1\) Feasibility of an Automatic Truck Warning System; FHWA-RD-93-039
information and data derived from on-vehicle measurements. Specific functions will differ among the three types of systems, but the overall functionality should be similar.

**Primary Function 1: Collect Data Required to Estimate Rollover Risk**

The primary function “collect data” consists of measuring or retrieving relevant data about the vehicle (characteristics such as weight and load, spring rates of suspension and structural components, and operating parameters such as speed and acceleration) and data about the highway feature (curve or ramp) that the vehicle is approaching.

**Primary Function 2: Estimate Rollover Risk**

The primary function of estimation of rollover risk consists of data validation, followed by computation of estimated risk based on the data and a valid model of vehicle (and perhaps driver) behavior.

The calculation of rollover risk involves assumptions about the intended path of the vehicle and prediction of near-term future vehicle speed based on current vehicle speed and acceleration. For open highway situations, it is reasonable to assume that the intended path is the lane in which the vehicle is traveling. For intersections and interchanges, risk should be estimated for plausible turning movements. If it is feasible to make allowance for variation in driver performance in accomplishing steering movements, inclusion of that variation could increase the accuracy of the risk prediction.

**Primary Function 3: Operate Warning Device(s)**

The primary function of operation of a warning device consists of turning on the device to produce warning signals at appropriate times, adjusting the type of warning signal and its urgency
to suit the circumstances, and turning off the warning device when the warning signal is no longer appropriate.

A warning signal should be produced when it is estimated that the vehicle’s risk of rollover exceeds a (predetermined) threshold if it is operated as projected, based on current speed and acceleration. Matching the type of signal and its urgency to the estimated risk of rollover in a given situation makes the system dynamic and hence more believable.

ALTERNATIVE SYSTEMS DESIGNS

Infrastructure Based Systems

Concept of Operations -- The concept of operations of an infrastructure based warning system is straightforward. Sensors deployed in or alongside the roadway just before a hazardous turn detect trucks and measure some characteristics of the vehicles. Based on those measurements and the known lateral acceleration demand of the upcoming turn, a roadside computer estimates the risk of rollover for the vehicle. If the estimated risk exceeds a threshold previously set by the responsible agency, the computer activates flashing lights or another signal to alert the vehicle’s driver to the rollover hazard.

State of Practice -- The state of best practice of such a system is illustrated by the previously mentioned demonstration project installed in three locations on the Washington, D.C. Beltway by Bellomo-McGee, Inc. In that project, piezoelectric, inductive loop, and optical sensors measure weight, speed, and height of passing vehicles as they approach freeway ramps. Based on those data, trucks are identified and classified by the local controller (computer), and separated on the basis of height (greater or less that 11 feet high) into “box” or “tanker”. Speed is measured at two points (allowing longitudinal acceleration to be estimated) and speed during the turn is
projected, allowing lateral acceleration in the turn to be estimated. If estimated lateral acceleration is higher than a preset rollover threshold for the identified class and type of vehicle, warning lights on a roadside sign are turned on until the vehicle passes the sign. Initial operation of the three sites is discussed in an interim report\(^2\) from Bellomo-McGee.

**Possible Extensions** -- The installed prototype includes state-of-the-practice components, and probably offers most of the accuracy and credibility of any feasible infrastructure based system. In their initial study, Bellomo-McGee did suggest other configurations, and others have suggested extensions of the infrastructure instrumentation. In particular, video imaging and other available optical devices have been suggested to give more precise classification of vehicle type and configuration. In their initial study in 1995, Bellomo-McGee also recognized that an integrated infrastructure-vehicle system offered the greatest accuracy of risk estimation; however, they concluded that such a system was not cost-effective at that time.

**Strengths of Infrastructure Based Systems** -- Perhaps the greatest strength of an infrastructure based warning system is that it is localized. It can be completely controlled and operated by a single entity, avoiding any inter-agency or jurisdictional conflicts. Likewise, data collection is all "local" (in the terminology of the requirements discussed in a previous section of this document), avoiding any need to transmit and receive information between roadside and vehicle.

**Weaknesses of Infrastructure Based Systems** -- The most important weakness of infrastructure based systems is the inherent difficulty of determining the actual rollover behavior of loaded trucks in such systems. Even in postulated "extended" systems, trucks can only be segregated into types, and knowledge about their loads and load distributions is extremely limited. Rollover

threshold estimation therefore is quite uncertain and has potential for considerable error. As demonstrated at the Washington, D.C. Beltway installations by Bellomo-McGee, the agencies responsible for the infrastructure react to that uncertainty by setting very conservative threshold limits. Of course, low threshold limits lead to false alarms, and drivers react by losing confidence in the warnings and disregarding them.

Vehicle Based Systems

Concept of Operations -- In concept, a vehicle based rollover warning system measures the actual roll behavior of a vehicle under lateral acceleration. When the roll approaches unacceptable risk of rollover, an in-cab signal alerts the driver, either immediately or after the rollover risk has passed. On-board sensors can include both multi-axis force transducers on the fifth-wheel coupling between tractor and trailer, and sensors mounted on wheels or axles of the trailer. In addition, it is feasible to transfer data from a vehicle’s control computer (the “ECM”) to a data collection/rollover risk computer.

State of Practice -- In a system currently in development under a National Highway Traffic Safety Administration (NHTSA) cooperative agreement, roll behavior of a tractor-trailer combination is measured by sensing the forces on the fifth-wheel coupler between tractor and trailer. The measured forces are then used in combination with a complex and precise computer model of the vehicle suspension to estimate how closely the vehicle approaches rollover. The estimated risk is to be displayed on an in-cab display, allowing the driver to learn how his vehicle behaves and avoid high-risk driving.

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3 Heavy Vehicle Intelligent Dynamic Stability Enhancement Systems. NHTSA Cooperative Agreement, No. DTNH22-95-H-07002
Possible Extensions -- The NHTSA project was originally focused on tractor based sensing, to avoid difficulties in communication between the tractor and trailers, and to make the system independent of which particular trailer happens to be connected. The project leaders report that there is some challenge to precisely inferring trailer behavior (which normally dominates rollover risk) from tractor measurements alone. They suggest that an instrumented trailer -- a “Smart Trailer” -- could simplify and improve the accuracy of risk estimation, although some difficulties in that approach are recognized. In addition, it is mentioned in project documentation that infrastructure information would be required to allow prediction of rollover risk in time for a driver to take corrective action.

Strengths of Vehicle Based Systems -- A compelling strength of vehicle based systems is the ability to measure the actual roll behavior of a specific vehicle with a particular load, rather than relying on assumptions about generic types of vehicles (as an infrastructure-only system must). This specificity can greatly improve the credibility of any warning signals and ensure that the driver knows that such signals do indeed refer to his or her vehicle. An additional strength of vehicle based systems is that such systems keep the responsibility for vehicle safety with the driver and vehicle, rather than shifting responsibility to an external agency. Vehicle-only systems also avoid external communications, except for the communication link between trailers and tractor.

Weaknesses of Vehicle Based Systems -- An important shortcoming of vehicle based systems as they are now being developed (see Ref. 3) is that they provide only after-the-fact warning to a driver. As the systems are now being developed, they continuously evaluate the roll attitude of the vehicle, but have no access to data about the highway. If a vehicle actually approaches rollover, one can argue that the driver would be dangerously distracted by a warning signal at that time. Hence, the indication of approach to rollover might be delayed until after the danger has
passed, and then used to train the driver to avoid similar risk in the future. However, no assistance is provided to the driver to avoid a particular rollover risk that is imminent.

**Integrated Vehicle/Infrastructure Systems**

**Concept of Operations** -- An integrated system could incorporate both on-board vehicle data collection and transmitted or stored data about infrastructure in the immediate path of a vehicle. The system could then use the combined data to make an accurate and timely estimate of rollover risk. When the risk exceeded a threshold, a specific warning could be given directly to the driver of the vehicle at risk in time for corrective action to be taken. An integrated system therefore could combine the precise measurement of specific vehicle roll behavior with timely information about lateral acceleration demand, allowing a timely and credible warning. (This possibility is mentioned in reports on both infrastructure-only and vehicle-only system projects.)

The on-board sensor suite could include any instrumentation available or developed for a vehicle-based system. In one simple implementation, the roadside equipment could consist simply of a transmitter to broadcast data about the lateral acceleration demand of an approaching curve. A suitable on-board receiver could relay the data to an onboard computer to be used for timely estimation of rollover risk.

**State of Practice** -- No current or existing project includes all of the components of an integrated condition responsive rollover warning system. However, all of the components are available, and could be integrated into a demonstration of principle. After successful demonstration of principle, the components could of course be engineered to perform optimally in a deployable system. Available components include commercial products to measure weight or weight transfer on individual tractor and trailer axles and wheels and collect those data in the tractor cab, commercial products that are suited to transmit infrastructure data to a moving vehicle, commercially available...
cab-mounted microcomputers capable of running risk-estimation algorithms in real time, and commercial products that are suitable to provide in-cab warning signals to a driver. In most of these categories, there is more than one available option.

**Possible Extensions** -- Demonstration of an integrated condition responsive truck rollover warning system appears to require only system integration and test, at least for a proof of principle demonstration. After proof of principle, the next requirement for deployment would be agreement on a minimal set of standards for infrastructure data by responsible government agencies at appropriate levels. Once the appropriate standards were set, any system extensions would amount to product development and marketing by industry.

**Strengths of Integrated Systems** -- The principal strength of an integrated system for rollover warning is that it has available all the data required for precise and timely estimation of rollover risk. Almost equally important is the opportunity for warning signals to be presented to a specific driver with high probability that they will be perceived and believed. An additional significant benefit is that decision making about corrective action remains with the driver of the vehicle, who is ultimately responsible for the performance of the vehicle.

**Weaknesses of Integrated Systems** -- The major apparent weakness of proposed integrated rollover warning systems is their technical and institutional complexity. Because such systems will use components that are in both the vehicle and the infrastructure, with information transmitted between the two, their operation will span different engineering disciplines, different political jurisdictions, and public and private property lines.
COMPARISON OF ALTERNATIVE SYSTEMS

Feasibility -- Technical feasibility of an infrastructure based warning system has been demonstrated by the Bellomo-McGee project, although the interim report discusses some improvements suggested for robustness and reduced maintenance effort. Potential extensions of the infrastructure system such as video image analysis that involve application of technology tested elsewhere are also imminently feasible. Institutional feasibility is also reasonable to assume, since such systems would not represent a major departure from accepted signaling practice. Economic feasibility has yet to be demonstrated; if the low credibility of such systems leads drivers to ignore them, few benefits will result from their deployment.

Technical feasibility of a vehicle based system is being evaluated as part of the NHTSA-UMTRI rollover stability enhancement project. Their results to date suggest that such a system can be built and will work. The system is vehicle based, so the primary institutional issue is whether rule making to promote the installation and use of such a system is in the public interest or public subsidies are indicated. Economic feasibility, if it can be demonstrated, could avoid the institutional questions if truck operators believe it is in their best interest to install and use such systems.

Technical feasibility of an integrated system is yet to be demonstrated, but all of the components exist as parts of other functional systems; the outstanding technical issue thus becomes a systems integration issue. Some possible integrated systems appear to cost little more than vehicle based systems, and economic analysis that indicates feasibility of vehicle based systems would support integrated systems.

Effectiveness -- The Bellomo-McGee analysis of results from the Washington, D.C. Beltway infrastructure based system concluded that trucks decreased their speed more when the signs were
activated. This beneficial result is taken as evidence that such a system would in fact help prevent rollover accidents, though the infrequent occurrence of such accidents makes it difficult to demonstrate that conclusion statistically.

The NHTSA vehicle based system is still being developed, so its effectiveness is a matter for conjecture. Participants in the project make the plausible argument that a credible in-cab display will avoid the problem of drivers who assume “That sign doesn’t mean me.” The system potentially can be quite precise and accurate in its estimation of rollover risk, so its warnings can have good credibility. However, the system inherently provides an after-the-fact indication of rollover risk, and therefore cannot help a driver in an unfamiliar situation where safe speed is not obvious. Nonetheless, such a system seems likely to be more effective than an infrastructure based system.

An integrated infrastructure/vehicle warning system has yet to be demonstrated, so effectiveness likewise is yet to be demonstrated. Such a system would share the accuracy, credibility, specificity, and in-cab salience of the vehicle based system, and would also provide timely advance warning, to allow drivers to reduce their speed in unexpected high-rollover-risk situations.

Cost — System costs can be estimated for the three types of systems compared in this paper. For the existing prototype infrastructure based system, costs are known and the uncertainty of cost estimates is primarily associated with extrapolation from the prototype to possible deployed systems. The other two types of systems consist of existing components in systems to be integrated and demonstrated; associated system costs are yet to be determined. (A Mathcad™ document available from the authors contains some reasonable assumptions about cost, but other assumptions can be made.)
The Bellomo-McGee infrastructure installations cost about $220K per site. Details of the cost breakdown are available in the referenced report. Extension of the sensor suite in accordance with the suggestions for enhancement probably would not greatly increase the installed cost. Because such systems would be based largely on state-of-the-practice sensors, computers and communications, in configurations already commonplace, it seems unlikely that major reductions in installed cost would be realized if such systems were widely deployed. The expense, of course, would be borne entirely by the agencies that install such systems. The trucking industry would share the cost only through taxation, since no equipment would be installed in vehicles.

The on-board instrumentation for the prototype system being built for NHTSA by the University of Michigan Transportation Research Institute (UMTRI) is estimated to cost about $6000 per tractor. If smart trailer sensors are included, the per-vehicle (tractor and trailer) cost is expected to be about $6500. However, unlike the case with the infrastructure based system, cost of this instrumentation is very likely to decrease as a result of the typical learning curve associated with computer equipment and other integrated circuitry. In somewhat similar instances involving the automotive industry, a cost reduction of several times has occurred. It is not unreasonable to hope that installed cost could fall to less than $1000 per vehicle. Because the instrumentation would be entirely on board the vehicle, the cost presumably would be borne by truckers, perhaps with some public subsidy.

An integrated rollover warning system would involve both infrastructure costs and vehicle costs. It would be possible to partition such a system in more than one way, and the partitioning would change the portions of total cost borne by each sector.

One straightforward system partitioning could consist of essentially the on-board instrumentation being prototyped by UMTRI, supplemented by a communications receiver added to the vehicle’s
equipment and corresponding infrastructure broadcast equipment. For that partitioning, the incremental cost of advance warning capability would amount to the cost of the transmission and reception devices. There are products already on the market that are sufficient, at an added cost per vehicle of a few hundred dollars and an infrastructure cost per installation of a few thousand dollars. Prototype products being demonstrated now could reduce that incremental cost to a few tens of dollars per vehicle and a few hundred dollars per infrastructure installation.

Benefits -- “Benefits” of a truck rollover warning system are primarily the costs avoided by the prevention of rollover incidents. There are two obvious categories of accident cost -- cost to truckers, and cost to taxpayers. The associated Mathcad™ document contains a discussion of and numerical assumptions about rollover system deployment costs and rollover accident costs. In the document, large-scale deployment of systems is assumed; in practice, local and state agencies would probably deploy infrastructure components only as funding permitted, with priority installation where there is a history of rollover accidents. In-vehicle components would probably be purchased and installed only if the trucking industry perceived a clear financial advantage or were responding to regulations. The Mathcad™ document is available as a computer file that can be entered into Mathcad™, an engineering software product that runs on personal computers. The assumptions could then be modified and costs recalculated to reflect the changed assumptions.

For truckers, an accident results in damage to the vehicle, damage to or loss of cargo, and loss of revenue until the vehicle is returned to or replaced in service. In addition, truckers can be liable for damage consequent to a rollover, including damage to the infrastructure and some of the cost of cleanup.
The costs of injury and death are major social costs of truck rollover accidents; the National Safety Council offers guidelines\textsuperscript{4} about incorporation of those costs in system analysis. In addition, the traveling public suffers delay from most rollover accidents; the cost of that delay can be estimated in economic terms. Some rollover accidents result in release of hazardous materials, and there is an environmental cost to the public which is real but is difficult to quantify with available data.

Governmental agencies must expend resources to manage rollover accident response, and must perform any required infrastructure repair and environmental cleanup.

\textbf{INSTITUTIONAL ISSUES AND CONSTRAINTS}

Assuming that a condition-responsive truck rollover warning system (or systems) proves to be technically and economically feasible, the acceptance and utility of the system will be dictated to a large extent by institutional issues. Among these are: jurisdictional and agency issues; liability and legal issues; and privacy and personal issues. It follows that the design and implementation strategy of a truck rollover warning system must consider the pertinent institutional concerns from the outset, and that appropriate input should be gathered from all the stakeholders as part of the system development and selection processes.

In order to gain insight into the many institutional issues and constraints relating to the proposed truck rollover warning systems, interviews were conducted with selected interstate shippers, state and local government officials, and an ADVANTAGE I-75 contact. Representing the shippers, the interview sample included companies operating large and medium-size fleets, as well as both common carriers and private carriers. In the government sector, officials of the Tennessee DOT, \textsuperscript{4} \textit{Accident Facts for 1995}, National Safety Council
Knox County, and the City of Knoxville were queried. Finally, the input and comments of Mr. Don Hartman of the University of Kentucky (representing ADVANTAGE I-75) were obtained, since the goals and issues of the ADVANTAGE I-75 program are so similar to those of the proposed program to implement a network of truck rollover systems.

It should first be emphasized that input from the interviews clearly supports the need and strong backing among all the stakeholders for the development of the truck rollover warning system(s) that is being proposed. In addition, there are already some areas of consensus and common concerns relating to the following institutional issues:

1. The leadership and work force in the trucking industry already recognize the competitive advantages of implementing advanced technologies (to enhance safety and operational efficiency) on a wide-scale basis. The industry support for new technologies is strong, if it can be shown that the technology is useful and cost-effective.

2. Previous and existing ITS programs and demonstration projects have set the stage for multi-agency, public-private sector cooperation. Thus, many of the institutional concerns and barriers which could impact the implementation of a truck rollover warning system have already been overcome or discounted. The institutional climate for deploying a condition-responsive truck rollover system is favorable, again if it can be shown that the technology is useful.

3. Related to points 1 and 2 above, there is generally a concern that a truck rollover warning system, although technically feasible, will not provide a “practical” solution to the rollover problem. In talking with “truckers” and operators, they cite the great number of variables involved and the timeliness of the rollover warning as major
deterrents to developing an effective warning system. In fact, it was surprising to learn of the “strong preconceptions for failure” which already exist. For there to be institutional acceptance of a truck rollover warning system, these preconceptions must be countered from the beginning with the demonstration of accurate and reliable prototype systems.

4. Institutional issues become more numerous and complex as the number of players is increased. This certainly has been the experience with the ADVANTAGE I-75 project. There is general support for a rollover warning system architecture which minimizes the number of government agencies which must coordinate, and also for an architecture which places most of the control and oversight at the lowest possible level.

Several of the specific concerns identified in the interviews are discussed in some detail in the subsections which follow.

**Jurisdictional Issues**

As noted previously, the truck rollover problem is most pronounced in the urban and suburban environments where traffic concentrations are the highest and right-of-way and cost factors often constrain the design of interchange ramps and transition areas to the detriment of large vehicle safety. Unfortunately, these same environments typically have the more complex jurisdictional relationships, involving numerous local, regional and state agencies with varying goals and viewpoints. Also related to governmental affairs, there are most typically “layers of government” and “divisions of governmental responsibility” which must be coordinated and which surely impact system selection and operations.

Some of the more prevalent jurisdictional and agency issues are enumerated and briefly described below. This listing is not intended to be inclusive at all, but rather to illustrate the types of
concerns which will need to be addressed when designing and selecting the final system or systems.

1. Agency responsibilities, staffing, and priorities change over time. In particular, local and state politics and funding can drastically change almost overnight. This reality must be recognized, and a system architecture which is minimally impacted by such instability is favorable.

2. The most complex type of system to manage in terms of the jurisdictional relationships may be an integrated warning system which relies substantially on both infrastructure and in-vehicle components to be functional. It is interesting to note that the ADVANTAGE I-75 official, based on his experiences with that program, strongly suggested that "as much of the instrumentation be placed in the vehicle as possible" in order to minimize the number of different state and local highway agencies which must invest resources.

3. Interstate trucking interests are not necessarily experienced in working with or well connected to local government entities. This suggests the need for coordination at the statewide level, or through a multi-agency planning group.

4. In the interviews, system maintenance, enforcement and accountability surfaced as critical jurisdictional issues which must be addressed. The levels of resources and competency in each of these areas within individual agencies is a key institutional issue.

Liability and Legal Issues
In the truck safety arena, liability exposure and related costs can represent a major incentive or major obstacle to the adoption of new technologies. This certainly will be the case with a condition-responsive truck rollover warning system. This issue is one of the more difficult matters to handle because the various stakeholders have traditionally approached risk assessment and management from different perspectives. In addition, the public and private sectors have vastly different organizational cultures when it comes to legal/liability issues. It will be important to consider the liability exposures and legal responsibilities of the various stakeholders in the system architecture.

It is significant to note that most of the trucking interests did not feel that a truck rollover warning system would have negative liability impacts. On the contrary, such a system could most likely reduce overall liability exposure by reducing accidents. One industry official cited his company’s experience with GPS fleet tracking systems with speed monitoring and other performance measuring attributes. He indicated that the tracking technology had actually reduced liability risks and saved on insurance costs. Government officials were less certain about the liability impacts in the public sector. Generally, they said that any system which improves safety, regardless of who is responsible for the system, will be a welcome addition. Some officials, however, cited concern over the “reverse liability impacts” i.e., what would be the effect of not installing a warning system if such a system was available.

Another area of concern relates to federal/state regulations and standards which may be impacted or which may be needed in order to implement a warning system network at the national level. The ADVANTAGE I-75 program, for example, had to overcome the barrier of changing federal vehicle standards which related to windshield visibility. Such issues, if not foreseen, can cause delays and increased costs.
Privacy and Personal Issues

The deployment of a condition-responsive truck rollover warning system, whether it is infrastructure-based, vehicle-based, or a combination system, could generate considerable information about vehicle travel routes, loads and cargo type, vehicle speeds, and driver performance measures. The uses of such data for safety management, roadway design, and operations optimization would be a significant secondary benefit of a nationwide network of truck rollover warning systems. However, these same data may represent a threat to a company or individual driver’s privacy. From the perspective of a private company, the existence of detailed route and cargo data could threaten the company’s competitive advantage. Also, there may be a fear that such information would be used by government to expand trucking industry taxation and regulation. These concerns for awhile delayed the ADVANTAGE I-75 project development. As a result, there have been a number of safeguards designed into the data collection and retrievals systems to limit the accessibility and future use of the data. Similar safeguards may be warranted for the proposed truck rollover warning system.

Individual drivers, on the other hand, may fear that the driver performance and other data may be used to impose penalties or fines for unsafe behavior, or at the least, reduce their feeling of independence and individuality. Older generation truck drivers have also shown some reluctance to using new technologies. Industry officials cited similar concerns in implementing speed recorders, GPS tracking systems, video monitoring systems, and other devices. Labor unions have reacted to new technologies with considerable caution, and have required strict limitations.

Summary

This discussion of institutional issues and constraints was not intended to be inclusive or to suggest a preference for one type of system over another at this time. Rather the issues raised are examples of the types of concerns which should be considered in designing and selecting the most
appropriate truck rollover warning system. It will be important to consider institutional issues from the outset and to draw heavily upon the experience gained in other ITS programs and demonstration projects. It will also be important to seek the input of the key stakeholders throughout the development process.

**SUMMARY AND CONCLUSIONS**

Technical and economic feasibility of a condition responsive truck rollover warning system both appear to be quite likely, especially if a credible system can be demonstrated. This evaluation of alternative system designs indicates that an integrated system that takes advantage of knowledge about both vehicles and the infrastructure can probably be built with state-of-the-practice components.

Analysis of system deployment costs and rollover accident costs that could be avoided further indicates that, subject to the validity of the assumptions, the general public and the trucking industry would quickly recover the investment in deployment of such a system. The analysis suggests that it could be to the public advantage for taxpayers to help defray the costs of implementation of truckers' on-board equipment.