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EVALUATION OF AN EXPANDED SATELLITE BASED MOBILE COMMUNICATIONS TRACKING SYSTEM

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ABSTRACT

Since the terrorist events in the United States on September 11, 2001, the Federal Motor Carrier Safety Administration has been testing and evaluating cargo tracking technologies to improve the safety, security, and efficiency of commercial motor vehicle operations. While satellite-based systems used for tracking vehicles and cargo provide sufficient geographic coverage in the majority of the United States, there remain several vital regions that are uncovered and difficult to monitor. One such region is Alaska, where officials are particularly concerned with the hazardous materials shipments that are transported parallel to the Trans-Alaska Pipeline. This article analyzes the risks and benefits associated with adopting an Expanded Satellite-Based Mobile Communications Tracking System to monitor hazardous materials and high-value cargo in Alaska. Technical and acceptance risks are evaluated against the communication, safety, security and real time information benefits that the system provides. The findings indicate that the system provides a significant communications upgrade relative to previously available technology.

Since the terrorist events in the United States on September 11, 2001, the Federal Motor Carrier Safety Administration (FMCSA) has been testing and evaluating technologies to improve the safety, security, and efficiency of commercial motor vehicle operations. Several key studies have evaluated vehicle and cargo tracking systems. These systems provide automated updates of location information to a dispatcher on a regular basis. They also include the ability to share critical information with carrier-authorized third parties, such as public sector agencies. While satellite-based systems used for tracking vehicles and cargo provide sufficient geographic coverage in the majority of the United States, there remain several vital regions that are uncovered and difficult to monitor.

One such region is Alaska, where officials are particularly concerned with the hazardous materials (HazMat) shipments that are transported along the Dalton Highway from Prudhoe Bay in the north to Fairbanks and other cities in the south. The Dalton Highway runs parallel to the Trans-Alaska Pipeline. If a terrorist attack were to occur in Alaska, authorities believe that the pipeline would be one of the likely first targets and a hijacked

HazMat shipment would be a convenient weapon. Additionally, the vast geographic expanse and harsh climate of the Alaskan region, as well as limitations in currently available communications systems, make vehicle breakdowns and other emergencies potentially life threatening situations for vehicle operators.

This article analyzes the risks and benefits associated with adopting an Expanded Satellite-Based Mobile Communications Tracking System (ESCT) to monitor hazardous materials and high-value cargo in Alaska. One major goal of this system is to improve communications in the event of an emergency, while enhancing trucking operations en route and for each phase of movement—pick up, delivery, receipt, and storage.

After evaluating the risks and benefits associated with the ESCT, it was found that benefit estimates outweigh the potential risks. The system provides a significant communications upgrade relative to previously available technology. The safety and security improvements have already had an effect on the operations of those carriers participating in a pilot study, and the system has found wide acceptance among employees, while the potential of the real time information provided by the ESCT is yet to be fully realized. The system will still require further improvements, since the satellite coverage of the region left several areas uncovered. However, with the limited risk involved and the potential for benefit, implementation of the ESCT on a wider scale would result in a significant improvement in the tracking of cargo in Alaska.

This article is organized as follows: the following section describes the new satellite system and presents the guidelines under which the satellite system was tested; the risks associated with adopting the new system are then described, analyzing both technical and acceptance risks; the various benefits of the system, including improvements in communication, safety and security, and the use of real time information are then presented; and the final section presents the conclusions.

SATELLITE SYSTEM REQUIREMENTS AND TEST GUIDELINES

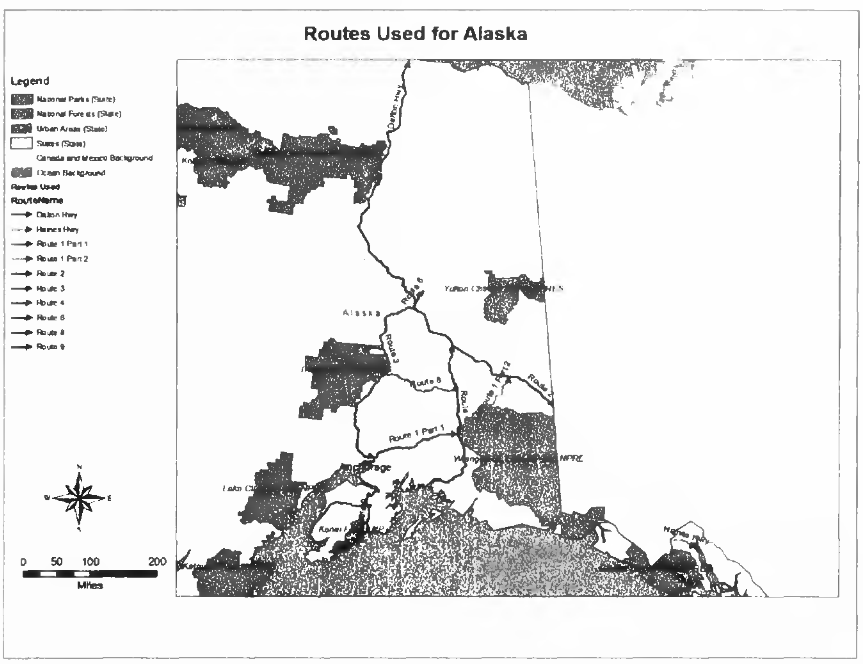
Travel on Alaskan highways is often a very dangerous undertaking. Trucks must traverse some of the most remote, harsh territory in the U. S., with 250 mile long stretches of highway that have no rest stops and no gas stations, while temperatures may reach -80° F. Truckers regularly deal with vehicle breakdowns caused by extreme temperatures, or the poor quality of the potholed roads. Under these conditions, it is of critical importance to be able to maintain some type of contact with drivers in the event of an emergency. However, this has not been possible in the past. The satellites used for tracking vehicles in the 48 continuous states do not provide coverage in Alaska. Cell phone coverage is isolated to urban areas, while CB radio availability is often intermittent due to the mountainous terrain. Therefore, a new system was required in order to extend vehicle tracking to most of the region.

Qualcomm, Inc. was selected to develop an expanded satellite system for the region. The new system required the use of a satellite positioned such that contact with the entire region could be maintained at all times at a reasonable cost. The orbits used by tracking systems for the 48 continuous states do not reach far enough to cover the majority of Alaska. Modifying those orbits would be cost prohibitive for the volume of traffic to be monitored. A geostationary satellite that has an orbit allowing for coverage in Alaska was selected for the system. Because the geostationary satellite is lower on the horizon, the antenna on each vehicle was adjusted such that the elevation angle was lowered. Further, a high powered transceiver component was used to ensure that the satellite could reliably communicate with the mobile unit even in northern Alaska, where the sensitivity of the satellite was the weakest. With satellite coverage extended by this new system, testing could begin to analyze the risks and benefits associated with the new service.

The three month test period began in mid-October 2005. The trucking routes of interest are detailed in Figure 1, covering over 2100 miles of roadway. Four carriers participated in testing the satellite system, with a total of 100 tractors outfitted with mobile transceiver units. The components required for each tractor were a dome antenna mounted on the roof of the tractor, a mobile communication unit (keyboard) installed in the cab, a panic button mounted inside the cab, and a wireless panic button that the driver could carry on a keychain. Messages from the tractor are relayed through a commercial Network Management Center (NMC) to the carrier's host system. Several technologies were evaluated during the test, including a messaging system that allowed for text or macros to be sent between the dispatcher and driver, location and mapping of tractors, and a system to send out panic messages in the event of an emergency.

During the three month test period, certain technologies were evaluated regularly on a day to day basis. Each mobile unit would take a reading to determine if satellite tracking was available at the unit location, and if so, to generate a position report. The units each took a reading every 15 minutes while the vehicle was in operation, resulting in over 263,000 position reports during the test. Over 2000 regular messages and 50 panic messages were sent during daily operations over the three months. In addition to the day to day testing, an evaluation team conducted tests during two site visits with each carrier. These site visits allowed for controlled testing of all technologies, in particular those that were infrequently used, such as the panic buttons.

FIGURE 1
ROUTES OF INTEREST IN ALASKA



Source: Battelle, 2006; Roadway Data: Esri Street Map

RISKS

For the purposes of this study, two risks were analyzed when evaluating the ESCT, technical risks and acceptance risks. The technical risks are those associated with how reliably the system may perform under day to day operating conditions. System performance is defined in two ways: message transmission latency and data quality. Based on testing during site visits, both latency and data quality do not appear to be significant technical risks. The acceptance risks are those associated with the willingness of employees or customers to adopt the system and use it on a regular basis. Both employees and customers appear to be very likely to utilize the ESCT given their experience with the test configuration.

Technical Risks

Latency was measured as the elapsed time from when a message was sent from the mobile unit in the vehicle until it was received at the carrier's host system. The current version of this system cannot provide a time stamp when the message was actually sent from the mobile unit. Rather, the system creates a time stamp when a message is received at the NMC and again when that message is forwarded to the carrier's host system for viewing by the dispatcher. Therefore, in order to accurately determine the amount of time that elapses between the driver sending the message and the dispatcher receiving it, the send time must be manually recorded. This only occurred during the two site visits and not during regular daily testing. It is important to note that these tests were run when the vehicle was positioned with a clear line of sight to the satellite. Attempting to transmit messages without a clear line of sight, such as in a remote area, should result in a greater latency period.

During the staged test, the evaluation team recorded the time (as displayed on the in-cab mobile unit) that the message was sent by the driver. This was compared with the automated system logs for time of receipt at the host system. The send and receive times for return messages (from the host to the mobile unit in the truck) were also recorded to calculate system latency for these messages. Tests were performed for regular text messages, macros, and panic messages. The tests for each message type were performed no more than four times per carrier over the course of two staged tests. This results in a small sample size. However, it is still possible to draw some conclusions from the results in regards to technical risks.

In evaluating the results of the testing, a set of criteria must first be established to provide a benchmark for performance. The messaging service provided by the ESCT system closely parallels the Short Messaging System (SMS), or text messaging, used by cellular providers in many ways. Given that this system is to fill a role that cellular providers may take under less extreme conditions, we may apply the standards of the mobile telecommunications industry to the ESCT system. However, this industry is somewhat reticent to reveal how well their systems perform. Therefore, research in this area has been inadequate and the analysis was based upon the limited information available.

Some software developer tool kits can specify a time delay for sending a message, but it is dependent on operator network traffic, congestion, optimization, etc. Most findings report on the degradation of service under extreme circumstances with very high messaging volumes, but even this can be revealing as standards have changed with the significant increase in text messaging. The delay for a high volume event from a few years ago, New Year's Eve of 2003, was several hours (Sturgeon, 2004), while some companies today are promising the delivery of messages in less than 15 seconds (Wieland, 2006). The latter criterion is rather stringent and would be difficult to guarantee under any circumstances. Based on the requirements of the carriers participating in this study, the criteria in Table 1 were established. Given these standards, the metric for "excellent" service should be regularly satisfied, with a maximum transmission delay of two minutes for regular messages and one minute for panic messages.

Table 2 presents the latency times for regular text messages sent from the driver to dispatcher and dispatcher to driver. The average latency time for messages sent from the driver to dispatcher is 50.7 seconds, while dispatcher to driver is 69 seconds. Both of these values are well below the two minute criteria for "excellent" service. Only one message required more than two minutes for transmission, while four were over one and a half minutes.

Table 3 presents the latency times for macros sent from the driver to dispatcher and dispatcher to driver. The average latency time for messages sent from the driver to dispatcher is 70.6 seconds, while dispatcher to driver is 77 seconds. Both of these values are well below the two minute criteria for "excellent" service, but greater than the average values for regular text messages. However, there are two macro messages that required significantly more time, with one transmitting in over two and a half minutes and the other in almost four and a half minutes. Also, the median value for messages from the dispatcher to the driver is 46 seconds for the macros while it is 62.5 for the regular text messages. Furthermore, the average latency value for the macros is 53.5 seconds when the message requiring 265 seconds is removed. These inconsistencies are difficult to justify given the limited data available. It would appear that sending a macro generally results in an "excellent" latency time, with the two delayed messages resulting in a rating of "appropriate" based on the carrier required expectations.

Table 4 presents the latency times for panic messages sent from the driver to dispatcher through the use of the wired and wireless panic buttons. The wired panic button is installed in the cab, while the wireless button is held by the driver. A metric for these messages for "excellent" service is transmission in less than one minute. Based on the intended usage of this tool, this is an appropriate standard. The average for wired messages was 52 seconds, while wireless messages required 54.1 seconds. Two messages sent during testing did not satisfy the criteria for "excellent" service, with one of the messages requiring almost two minutes for transmission. One message represents 6 percent of all those transmitted, which is a reasonable rate of occurrence for messages with an "appropriate" service level.

The majority of messages sent, whether text, macro or panic message, were transmitted with a latency time that could be qualified as "excellent." One out of 28 text messages, two out of 20 macros and two out of 24 panic messages could be classified as "appropriate." While the test sample sizes were not large, the results indicate that message latency is not a technical risk. Sending messages while the vehicle does not have a direct line of sight to the satellite should result in a greater latency. This potential problem was not addressed with these tests. However, concerns over coverage areas will be discussed in a later section.

Data accuracy was determined by comparing the content of the sent message with that of the received message. Similar to the latency tests, data accuracy was evaluated with both messages

TABLE 1
COMMUNICATION LATENCY EVALUATION METRICS

Rating	Panic Alert Requirements	Other Messages
Excellent	Less than one minute	Less than two minutes
Appropriate	Between one and three minutes	Between two and five minutes
Degraded	Between three and five minutes	Between five and ten minutes

TABLE 2
LATENCY MEASUREMENTS FOR TEXT MESSAGES (IN SECONDS)

Direction	Staged Test	Carrier 1	Carrier 2	Carrier 3	Carrier 4
Driver to Dispatcher	1	39	34	77	21
		31		31	
	2	63	40	109	77
		78	24	30	56
Dispatcher to Driver	1	66	70	63	134
		62	112		106
	2	43	21	51	59
			41		

TABLE 3
LATENCY MEASUREMENTS FOR MACROS (IN SECONDS)

Direction	Staged Test	Carrier 1	Carrier 2	Carrier 3	Carrier 4
Driver to Dispatcher	1		67	80	11
	2	65	67	67	154
				54	70
Dispatcher to Driver	1		89	21	265
				39	
	2	46	25	79	43
		86			

TABLE 4
LATENCY MEASUREMENTS FOR WIRED AND WIRELESS PANIC MESSAGES (IN SECONDS)

Direction	Staged Test	Carrier 1	Carrier 2	Carrier 3	Carrier 4
Wired	1	52	48	57	55
					58
	2	43	35	33	30
				109	
Wireless	1	58	66	47	46
	2	52	51		57
		56			

sent from the mobile unit and from the host system. The content of the message was manually checked by the test personnel at either location prior to transmittal and then compared with the message that was received. While this testing was somewhat limited, it was found that data quality was maintained throughout the process. All sent messages were identical in content to the corresponding received message. As with delays in transmission, there is little information available regarding data accuracy for the mobile telecommunications industry.

Acceptance Risks

These risks are associated with the willingness of employees or customers to adopt the system and use it on a regular basis. If those who are expected to use a new technology are not comfortable with it, or do not find it helpful, there is a good likelihood that the technology will not succeed. Several technology acceptance models have been developed in literature, correlating the characteristics of a technology with the potential for acceptance. One of the more commonly reported factors is a technology's ease of use, with models by Davis (1989), Ajzen (1991), Thompson et al.(1991), Venkatesh et al. (2003), and Moore and Benbasat (1991) considering this correlation. Additional theories on the factors that may correlate to acceptance pertain to the perceived usefulness of the technology (Davis, 1989), enhancement of on the job performance (Thompson et al., 1991), compatibility with the needs of potential users (Moore and Benbasat, 1991), and the anxiety generated by operating the new technology (Compeau and Higgins, 1995). If, for example, a technology is very easy to use and understand, the acceptance of that technology is not necessarily guaranteed, but there should be a greater likelihood of acceptance. Based on interviews with the participating carriers, information was obtained on how the satellite system was perceived by those who use the system. These perceptions relate to the factors described above such that an evaluation can be made as to the potential for acceptance.

The ease with which new users can learn the system is one of the more important technical factors related to acceptance. If drivers and dispatchers struggle with the system, then they are unlikely to adopt it for regular use. Based on independent interviews conducted with the carriers, this is not a problem. The carriers indicated that training required from a half hour to a few hours for each driver. None of the drivers or dispatchers expressed any concerns with significant technical problems that limited their capacity to learn how the system operates.

In addition to finding the system easy to use, most employees felt that the system was helpful in performing their job. Dispatchers found that it makes the load planning process simpler, as there is more visibility in terms of vehicle location and status. With the system, the dispatcher knows if a vehicle will arrive at a destination on time, such that the vehicle can then be used to pick up another load. In the past, alternate arrangements had to be made in order to guarantee that a load was picked up. This topic will be further explored in the section on real time information.

Drivers found the system helpful in that they feel safer and more secure, as they know that contacting a dispatcher in an emergency is much easier. The carriers believe that this is helping with driver recruiting and retention. However, some drivers have expressed the fear that the new tracking technology may allow their employer to monitor their performance more closely. While the carriers are not yet using the system to track driver performance, they have indicated a desire to do so. When this occurs, drivers will be less likely to cooperate in the implementation of the new system. Drivers can be slow to embrace new technologies, particularly when that may entail a loss of some privacy. The carriers will have to emphasize the positive aspects regarding safety and security in order to overcome any fears drivers may have. Also, if the majority of carriers adopt this technology, the drivers will have little alternative except to adopt and use it.

It is also important that the customer is willing to accept the system. This requires that each customer has a high level of comfort interacting with the system, whether information on load status is provided through a website or from a dispatcher. Customers have been very pleased with the system and everything that it has to offer. They find that the improved vehicle tracking is most beneficial. The system allows for the vehicle tracking information to be fed directly through the Internet so that customers have 24 hour access without continuously calling the dispatching center. Not only are customers pleased with this service, many are beginning to mandate it (including the Department of Defense).

Based on independent interviews, the acceptance risk is limited. The ease of use is not a concern as training requires a minimal amount of time. Employees find the system to be useful and to have the potential to enhance job performance, while customers also find the system to be very helpful. The only problem may arise as the system is used to monitor employee performance more rigorously. Drivers are often suspicious of any technology that allows an employer to look over their shoulder while they work, and this may lead to resistance on the part of the employees.

BENEFITS

This study focuses on three potential benefits that may be gained through the use of the ESCT system: improvements in coverage, safety and security, and the use of real time information. While coverage is spotty in limited areas, the overwhelming majority of routes see a significant improvement in the level of communication available. The carriers have already realized many safety and security benefits brought about by the satellite system, responding to emergency incidents more rapidly, while retaining more drivers by creating a safer environment. An additional benefit that is analyzed is the availability of real time information provided by the ESCT. With real time information, the carriers may utilize their fleets with an efficiency that was previously impossible. A simulation is used to determine that there may be a reduction in operating cost through a simple change in vehicle routing policy.

Improvements in Coverage

The most vital information provided during the test period indicates where and how often a vehicle is out of coverage (OOC). The OOC areas were established primarily through regular position reports that the vehicle transmitted every hour. A satellite availability check was performed every fifteen minutes by the mobile unit, with these results included in each hourly report. Determining the percentage of OOC reports relative to the total number of position reports for each location provides an accurate picture of where the most troublesome areas may be. Table 5 provides a summary of all OOC incident spikes for the routes (outlined in Figure 1) carrying the most traffic for the four carriers tested. This table indicates the location on the route at which the spike occurred, the probable reason for this occurrence, and the percentage of OOC incidents relative to total position reports. A primary objective for this system is to provide consistent communication with vehicles in remote locations, while two vital secondary objectives are to provide a secure form of communication that is not easily compromised and a method for transmitting more than just an audio signal, but data packets as well. In the majority of areas, this was accomplished. However, there are still some shortcomings.

In Table 5, those OOC incident locations where alternate forms of communication would most likely not be available have been highlighted. The incidents that are not highlighted occur in locations where the driver should be able to communicate with the dispatcher when the satellite system is unavailable, whether through the use of cellular phone, radio or land line. For example, in the case of Dalton Highway there were three locations with a significant number of OOC incidents where some other form of communication was accessible. Prudhoe Bay is a relatively urban area with cellular coverage, as

TABLE 5
LOCATION, JUSTIFICATION, AND OCCURRENCE PERCENTAGE OF OOC INCIDENT SPIKES ON ROUTES OF INTEREST
(OOC incident locations where alternate forms of communication would most likely not be available have been highlighted)

Route	Location	Probable OOC Justification	% OOC
Dalton Highway	Prudhoe Bay	Buildings/Overhead facilities	25-75
	Atigun Pass	Terrain – North/South valleys	>75
	Cold Foot Midway Point	Truck Stop/Facility	>75
	Baker's Knob	Truck Stop/Facility	<25
	Entire Highway	Terrain – North/South valleys; Oversized equipment	25-75
State Route 1	Anchorage	Terminals/Urban environment	<25
	Mileposts 220 – 240	Terrain – North/South valleys	<25
	Mileposts 65 and 85	Dining establishments	<25
	Mileposts 80 – 150	Terrain – West/East valleys	<25
State Route 2	Fox	Weigh Station	25-75
	Fairbanks	Terminals/Urban environment	25-75
	Mileposts 21 – 46	Terrain – North/South valleys	25-75
	Mileposts 61 – 80	Terrain – North/South valleys	25-75
State Route 3	Fairbanks	Terminals/Urban environment	<25
	Trapper Creek	Truck Stop/Facility	<25
	State Route 1 Junction	Truckers Domiciled	25-75
State Route 4	Delta Junction	Terrain/Facility	<25
State Route 6	Fox	Weigh Station	<25

well as radio accessibility. Cold Foot Midway Point and Baker's Knob are truck stops which should have personnel on hand to help in the event of an emergency, in addition to lines of communication that can access a dispatcher.

Consistent communication is available in locations such as truck stops and urban areas, even if the vehicle is out of satellite coverage. However, the security of this communication is not at the level provided by the ESCT system. As several carriers indicated, assigning a new load or rerouting a vehicle via CB radio is not an appealing option as this information is accessible to anyone using the same bandwidth. This information may be more securely transferred via the ESCT system. Many of these new vehicle assignments occur while the driver is within an urban area, where many of the OOC incidents occur. While the driver may easily contact help in the event of an emergency, a secondary objective of the satellite system is not realized, as the level of secure communication is limited. Another similar benefit that may be interrupted is the added reliability and accuracy that is gained through use of the system. With a larger fleet, there is a significant amount of radio traffic that can lead to missed or misheard messages and driver error. The satellite system allows for text messages with explicit instructions to be sent to a specific vehicle, eliminating most of the room for error.

Those OOC areas where an alternate form of communication is not available are rather limited throughout the network of tested routes. OOC incidents occurred along the entire length of the Dalton Highway, primarily due to terrain. Many problems occurred as trucks moving north/south on the highway dipped into valleys, losing the line of sight with the satellite in the southern sky. However, the percentage of OOC incidents was below 25 percent for much of the highway, with some spikes scattered along the route. The most significant spike occurred at the Atigun Pass, with more than 75 percent of location reports indicating no satellite coverage. As a truck moves up and down this pass, it is almost constantly surrounded by terrain that blocks the line of sight to the satellite.

The only other OOC areas where an alternate form of communication is not available with a percentage greater than 25 percent occurred in two locations along Route 2. While the coverage in these areas was not as spotty as at the Atigun Pass, there were a significant number of OOC incidents. The cause of these was similar to that for the Pass, as the trucks dipped into valleys on a route with a north/south direction. The other OOC spikes were below 25 percent, which may still indicate poor coverage, but not to the extent found on Dalton Highway or Route 2.

The six routes considered above cover over 2100 miles of highway. Excluding the scattered OOC incidents along the length of the Dalton Highway, OOC incidents occurred for over 25 percent of position reports on less than 100 miles of highway. This is less than 5 percent of the tested routes. The satellite system does have holes in coverage, particularly along the Dalton Highway. However, the coverage is rather expansive, particularly when compared to alternative systems of communications. Cellular coverage is limited to the southwest corner of the state and only to the urban areas, with no coverage for significant portions of the routes used by the participating carriers. The satellite system requires several improvements in order to provide a consistent level of coverage across all routes used by carriers, but it does allow for communication with a significantly larger region than previously available.

Safety and Security

The safety and security improvements that are provided through the use of the satellite system come primarily in two forms. One is the ability to maintain contact with vehicles in remote areas in emergency situations. The other allows for more secure transmission of information. In the past, all contact between a dispatcher and vehicle was via radio, allowing for easy access to outsiders. The text messages transmitted via the satellite prevent the open transmission of sensitive information. In this section, details are provided on how these improvements have already affected carrier operations and what additional benefits may be derived from the satellite system.

The extreme environment in which the Alaskan carriers operate is the cause of a significant number of vehicle breakdowns. Because of the regularity of these breakdowns and the harsh climate in which drivers must wait for assistance, it is important that the time required to react to a vehicle breakdown is minimized. While a quick response to these incidents improves fleet utilization, it also results in a greater level of safety for the driver. During the test, the carriers had the opportunity to use the system to respond to vehicle breakdowns several times. Each carrier found that it handled incident response very well, with drivers on certain routes requiring emergency assistance on a weekly basis. In the past, when a breakdown occurred in a remote location that was not within the reach of radio or cellular communication, the driver would have to wait for a ride from a passing vehicle and then contact the dispatcher when communication was reestablished. This would often require several hours. Now, the drivers simply use the panic button and wait for a response. The system has helped in retaining and recruiting drivers, as they feel safer because of the rapid response to emergency incidents. Also, the dispatchers feel that they can sleep soundly at night, knowing that their drivers are always within immediate reach of assistance in the event of a breakdown.

There were no events during testing that involved a breach of security. Clearly, such events are a very rare occurrence. However, based on the rapid response in the event of a breakdown, it can be assumed that response to a security event would be just as immediate, if not more so. In addition to improving response time, the satellite system may be viewed as a deterrent for hijacking or other breaches of security. The potential rapidity of response in an emergency situation should serve as a security feature in and of itself. The carriers also indicated that the system will allow for a more secure method of transmitting sensitive information. In the past, they have contacted drivers regarding loads they are carrying or picking up through the use of CB radio. This information is then accessible to competitors or other unwelcome listeners. By using the messaging system available with satellite communication, the transmissions become much more difficult to intercept.

Very little research has been done to relate vehicle tracking to improvements in safety and security. Therefore, it is difficult to quantify the benefit that can be gained in this area. Judgments must be made primarily from the qualitative results of the test. Based on carrier interviews, the satellite system has already made an impact on incident response over the brief three month test period and should soon be an aid in transmitting sensitive information. The realization of these benefits will continue as the system is further adopted. One important note is that the emergency response system can operate only when there is contact between the dispatcher and driver. As was shown in the previous section, there are sporadic pockets of the test region that resulted in a high frequency of out of coverage incidents. While the system has dramatically improved the safety and security of the trucks traveling in the test region, it could not be described as 100 percent reliable.

Real Time Information Applications

Given that the satellite system provides two-way communication between dispatchers and drivers, it is possible that operating efficiencies may be generated by deployment. In addition, since communications along certain routes in Alaska are so limited, these efficiencies may be quite substantial in this environment. As dispatchers have more access to real time information about vehicle location and status, vehicles may be rerouted to service new loads or to aid vehicles that have broken down. The satellite system provides a method for maintaining almost constant contact between the dispatcher and driver. In this study, a routing simulation was used to analyze the benefit of increased communication with vehicles on the road. A simulation was developed to determine how often a vehicle should be rerouted and to quantify the benefits associated with the information made available by the satellite system.

A great deal of literature covers the use of information systems to aid with vehicle tracking and routing. Much has been written on the benefits of tracking systems and how they are used for transportation management. Grainger (2005) examines the Iowa Rural Transit Integration Consortium and its use of an expansive ITS initiative implementing GPS and vehicle tracking to improve customer service, safety and security. Similarly, El-Gelil et al. (2004) describe how the Toronto Transit Commission created a more efficient bus schedule with accurate predictions on bus arrival times with a transit monitoring system. The movement of freight has also benefited, as many trucking firms are finding success through the use of trailer tracking systems, reducing trailer fleet size, improving customer service, and reducing the number of yard checks required (Mele, 2003). Freight transported by rail is better managed through the use of tracking systems, even in Alaska (Schiestl, 2004). The Alaska Railroad Corporation implemented a collision avoidance system, improving safety, protecting track maintenance personnel, and enforcing speed limits. They have also focused on improving customer service through reduced transit times and reliable delivery under frequently adverse conditions. This is just a sample of the many instances where using tracking technology to provide real-time information has improved a transportation network. Clearly, this technology has resulted in many operational improvements in other applications, with the search continuing for further advances.

The availability of tracking technology has led to a significant amount of research into how resources such as the ESCT system may best be further utilized. Some of that research is discussed here as it underlines the benefits that can be gained through the use of the satellite system and it provides motivation for the simulation that was performed for this study. Ichoua et al. (2005) exploit information about future events to improve decision making. They develop a strategy based on probabilistic knowledge about future request arrivals to better manage a fleet of vehicles, with promising results. Decision-making procedures for determining the optimal driver attendance time, optimal departure times, and optimal routing policies under time-varying traffic flows are developed by Kim et al. (2005). With a numerical study carried out on an urban road network in Southeast Michigan, they demonstrated significant advantages when using the real-time information in terms of total cost savings and vehicle usage reduction while satisfying or improving service levels for just-in-time delivery. Powell (1996) presents a hybrid model that handles the detailed assignment of drivers to loads, as well as handling forecasts of future loads. Numerical experiments demonstrate that his stochastic, dynamic model outperforms standard myopic models that are widely used in practice. Dynamic routing decisions for the application of ITS technologies are introduced by Wang et al. (2004) to improve freight mobility, reducing operational costs and enhancing service levels. Real-time traffic information was considered in their model, displaying the benefits of routing advisory systems that many logistics companies use in their day-to-day operations.

The pertinent literature on the use of tracking systems indicates that benefit can be gained through various methods. An effective use of tracking technology can result in improvements in vehicle routing, load planning and customer service. However, these improvements can only be generally described through the literature. In order to provide an analysis specific to the scenario under which freight is moved in Alaska, a simulation was developed with that scenario in mind. The simulation focuses on using the satellite system for more effective load planning, as this is where the most consistent improvements can be found.

With communication previously limited to certain populated regions, contact with a driver was difficult after the vehicle had left a pick up location. If a dispatcher had received information regarding a new load to be picked up or a vehicle was to be rerouted due to road conditions, there was only a small time window during which the dispatcher could provide a driver with alternative instructions. When deciding which vehicle should be used to deliver a new load, the dispatcher was only able to communicate with several vehicles in the fleet. Therefore, the vehicle that would be optimally suited to service the load may have been out of the range of those communication capabilities. Extending the range of communication should have an impact on assignment of loads to vehicles, vehicle routing, and operations in general.

The Simulation Model and Results

A model was developed to simulate a simple daily decision process describing how loads are assigned to vehicles, in particular delivery requests that occur over the course of a day that were not initially planned for. The model was used to evaluate how this process is affected by improved satellite communication and information availability. The simulation allows for a comparison of two scenarios:

1. Communication between the dispatcher and driver is limited such that loads may only be assigned to vehicles within the vicinity of the origin location.

2. Communication between the dispatcher and driver is via the satellite system such that loads may be assigned to vehicles that are no longer within the vicinity of the origin location.

Under the first scenario, when a new request to deliver a load arises, either a new vehicle or a vehicle that is still close to the terminal is assigned to service the load. The satellite system allows for communication with vehicles that are much farther from the terminal, so that the pool of vehicles available to deliver the load is larger under the second scenario.

For the purposes of the simulation, all vehicles will travel from Fairbanks to Prudhoe Bay along the Dalton Highway (the results for vehicles that travel from Prudhoe Bay to Fairbanks should be similar as the conditions for the problem remain the same). This highway was selected as a significant amount of freight is moved along the route and it connects two large terminals from which many loads originate. The distance between the two endpoints was set at 500 miles for the simulation.

At the beginning of the simulation, a fleet of vehicles is stationed in Fairbanks, with sufficient vehicles available to service all loads. The vehicles have a known capacity that is homogeneous across the entire fleet. Each vehicle incurs a fixed cost when it is used to service a load. Based on a survey of carriers, this fixed cost was set at \$150. A variable cost is also incurred for every mile the vehicle travels, with a value of \$2 per mile. It is assumed that the vehicle can travel 50 miles per hour on average. An initial set of loads to be serviced is known beforehand. Additional loads requiring service arise over time at random intervals. Loads may be combined on a vehicle as long as capacity constraints are not violated.

A new request may be serviced immediately by any vehicle in the fleet that has sufficient available capacity. A vehicle that is waiting at an endpoint may be used or a vehicle that is already traveling with a load may return to the endpoint to pick up the additional load. A time limit, T_{max}, indicates how long a truck may wait in the Fairbanks area to pick up another load. A partially loaded truck may wait at the terminal location for another load as long as this time constraint is not violated. This allows for multiple loads to be delivered by one vehicle. Another limit, T_{truck}, designates the maximum amount of time that a load may be on a vehicle after leaving Fairbanks. This limit serves two purposes: decreasing the value shortens the distance within which the terminal may communicate with vehicles on the Dalton Highway; and it prevents the same vehicle from continuously being called back to Fairbanks to service multiple loads. By adjusting this value, a scenario with limited communication could be compared to one in which the satellite system is operational.

This simulation was run over the course of a day until all loads were serviced. There were 17 loads to be serviced in a day for each simulation. The time intervals between service requests were randomly generated, ranging from 10 to 60 minutes. The load sizes were also randomly generated within a specified range. Three sets of intervals and four sets of loads, or twelve different problem instances, were used for each T_{max} and T_{truck} combination. The cost to service a set of loads was determined by adding the fixed cost of each vehicle used and the variable cost of the total distance traveled by all vehicles. The cost under limited communication was compared to that using the satellite system. Table 6 presents the results for several different combinations of T_{max} and T_{truck}. The percentage of cost savings indicates the amount that cost was reduced when the satellite system was used, while the vehicle reduction percentage indicates if fewer vehicles were used under the satellite system. The size of each load for this simulation ranged from 1 percent to 50 percent of vehicle capacity.

The values of T_{max} and T_{truck} were chosen based on carrier interviews. It was assumed that without the satellite system, reliable contact with the vehicles was available for half an hour after they had left the terminal. While this is low under many operating conditions, for the purposes of this simulation the value of T_{truck} under limited communication relative to that with satellite communication is most important. The values of T_{truck} listed are those used for simulations of communication with the satellite system. Therefore, the length of time that a vehicle is within reach of the dispatcher is two, three and four times greater than that with limited communication for the T_{truck} values of 60, 90 and 120, respectively.

There is some benefit to the satellite system with almost every combination of T_{max} and T_{truck}. As the value of T_{truck} increases, the benefit increases. This is because there is more time to contact a vehicle that has already departed the Fairbanks area to have it return to service another load. By increasing this radius of communication, the pool of available vehicles to utilize increases as well. A dispatcher will have many more options from a load planning perspective and costs should undoubtedly decrease.

In order to analyze the effect that load size may have on the benefit of using real time information, several simulations were run with varying size ranges. As indicated earlier, four different sets of loads were generated for each range and combined with three time interval sets. Table 7 presents the results from those

TABLE 6
PERCENTAGE COST SAVINGS AND REDUCTION IN NUMBER OF VEHICLES USED FOR DIFFERENT PARAMETER SETTINGS

T_{max}	120			90			60		
T_{truck}	120	90	60	120	90	60	120	90	60
cost savings percent	4.27	3.78	1.46	4.57	1.42	0	3.59	2.59	0.99
vehicle reduction %	8.33	4.72	1.67	6.94	2.78	0	4.32	3.27	1.19

TABLE 7
PERCENTAGE COST SAVINGS AND REDUCTION IN NUMBER OF VEHICLES USED FOR SEVERAL RANGES OF LOAD SIZE

Load size range	**1–100**	**1–50**	**1–10**	**11–20**	**21–30**	**31–40**
cost savings %	4.78	4.57	4.50	4.50	4.40	0
vehicle reduction %	6.02	6.94	5.56	5.56	5.56	0

simulations. The load size ranges are listed as a percentage of vehicle capacity. The T_{max} and T_{truck} values used for these simulations were 90 and 120, respectively. The benefit decreased marginally as the load sizes increased until there was no benefit with loads in the range 31–40 percent (there was also no benefit with loads in the range 41–50%). With larger loads, there are fewer combinations of loads that can be placed together onto one truck. For the results in the range 1–100 percent and 1–50 percent more vehicles were used and the overall cost was greater, such that there was more potential for improvement.

Every scenario simulated resulted in a cost savings of less than 5 percent. While this may not appear to be significant, in an industry where many carriers operate with margins below 5 percent, any cost savings is important. Also, the model used for this simulation was, while meaningful, a simplified version of actual operating procedure. When a vehicle returned to pick up a load, it had to return to the same location (the terminal) each time. This will probably not be the case in most situations, such that the distance the vehicle must travel to return to pick up a load will not be as great.

The reduction in the number of vehicles used may also have an important impact. While the model accounted for a financial fixed cost for each vehicle, there are additional less tangible costs that are related to the number of trucks on the road. By decreasing the number of vehicles utilized, other benefits may be realized. These may include an increased level of safety and security, as fewer vehicles are exposed to the remote conditions, and less wear and tear on vehicle fleets. Also, the carriers mentioned two additional benefits that this simulation does not take into account, savings that are a result of rerouting vehicles to aid other vehicles and to avoid traffic and weather problems. The carriers described a situation in which a vehicle had mechanical difficulties in a remote area, with another vehicle in the vicinity. In the past, communication with the other vehicle was not possible and a third vehicle was dispatched from the terminal area to aid the disabled truck. The satellite system could be used to instruct the driver of the second vehicle to aid the disabled truck, saving time and the cost associated with using a third vehicle. Because these events do not occur as frequently, it is difficult to simulate these scenarios to quantify the potential benefit of improved communication. However, as indicated by the carriers, such events do occur and the satellite system would be a very useful tool in responding more rapidly and efficiently.

CONCLUSIONS

After evaluating the risks and benefits associated with the ESCT, it was determined that the benefits outweigh the potential risks. For the purposes of this study, two risks were analyzed when evaluating the ESCT, technical risks and acceptance risks. Based on testing during site visits, both latency and data quality do not appear to be significant technical risks. The number of tests was limited, particularly when evaluating the tethered trailer tracking system, so it is difficult to make a conclusive statement on latency. However, the tests that were performed do indicate that messages are passed through the system with an acceptable amount of latency. The acceptance risks were primarily associated with the concern that employees have in regards to the system's potential use for monitoring performance. Both employees and customers found the ESCT easy to use, as training requires a minimal amount of time. Employees found the system to be useful and to have the potential to enhance job performance, while customers also found the system to be very helpful. The only problem may arise as the system is used to monitor employee performance more rigorously. Drivers are often suspicious of any technology that allows an employer to look over their shoulder while they work, and this may lead to resistance on the part of the employees.

This study focused on three potential benefits that may be gained through the use of the ESCT system, improvements in coverage, safety and security, and the use of real time information. It was found that while coverage is spotty in limited areas, the overwhelming majority of routes see a significant improvement in the level of communication available. The coverage must be further extended in order to provide a service that is reliable without fail. However, the ESCT is a major upgrade to previously available communication alternatives. The carriers have already realized many safety and security benefits brought about by the satellite system. They have been able to respond to emergency incidents more rapidly, while retaining more drivers by creating a safer environment. In addition to improving response time, the satellite system may be viewed as a deterrent for hijacking or other breaches of security. The potential rapidity of response in an emergency situation should serve as a security feature in and of itself. The carriers also indicated that the system will allow for a more secure method of transmitting sensitive information. However, this safety and security can only be extended so far as communication is available. With spotty coverage in some areas, the system can not be considered 100 percent reliable. An additional benefit that was analyzed was the availability of real time information provided by the ESCT. With real time information, the carriers may utilize their fleets with an efficiency that was previously impossible. A simulation was used to determine that there may be a reduction in operating cost through a simple change in vehicle routing policy. Real time information may also be used to reroute vehicles to aid other vehicles and to avoid traffic and weather problems.

The benefits associated with the ESCT system are widespread, with several yet to be realized. The most significant negative is the lack of coverage in some of the most remote areas in Alaska. Some of these problems may be remedied by adjusting the placement of the antenna on a vehicle, such as when an oversized load that is being hauled blocks the view to the satellite. Many of the out of coverage areas are so remote that any system will have difficulty maintaining a line of communication, short of locating a satellite even farther north or dotting the landscape with cellular towers. These are problems that must be addressed in order to achieve a goal of completely reliable communication along every route. However, the system does significantly expand communication for a majority of the region, while providing additional improvements to carrier operations.

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