2 BACKGROUND AND LITERATURE REVIEW

The purpose of this chapter is to provide a context for the need and purpose of this maintenance plan. First, ODOT's increasing reliance on intelligent transportation systems will be quantified. Second, comments collected from meetings with ODOT stakeholders will be used to identify the needs perceived by ODOT staff which may be address directly or indirectly through an ITS maintenance plan. Finally, this chapter will summarize findings from contacts with other transportation agencies and private sector firms to identify the potential availability and applicability of similar maintenance plans that may have been developed elsewhere.

2.1 Plan Context

Due to the increasing complexity and expense of adding to the capacity of the transportation system, transportation agencies are increasingly shifting from a construction focus to an operational focus. ODOT is no exception to this trend. In recent years, the Oregon Department of Transportation has begun to pursue a relatively aggressive program of ITS deployment in fulfilling the agency's mission. ODOT expects to continue in this direction in the future. ODOT's Statewide Transportation Improvement Program 2000-2003 (STIP) (2), which provides funding for transportation projects over the next four years, includes deployment of many ITS devices throughout the state. Moreover, the Oregon Intelligent Transportation Systems Strategic Plan: 1997-2017 (3), approved by the Oregon Transportation Commission in 1998, indicates that ODOT and other agencies throughout the state are planning to deploy an increasing number of devices in the future.

The extent of ODOT's existing and planned[1] ITS deployment is shown in Table 2-1. ODOT's statewide ITS inventory database was used as a starting point for determining existing deployment levels (4), with additional information gleaned from contacts with ODOT staff, including the ITS unit, and regional and district maintenance staff. Planned deployment quantities and locations[2] were based on a review of the STIP and the Strategic Plan, along with conversations with ODOT's ITS unit. While it is expected that the nature of ODOT's planned ITS infrastructure will change based on many factors, such as technological advancement, changing regional needs and fiscal constraints, the table nonetheless shows a clear trend for increased deployment of ITS devices.

2.2 Stakeholder Meetings

In Oregon, ITS devices have historically cut across jurisdiction lines for operations and maintenance. In order to ensure that this plan would satisfactorily identify and address the needs of the agency overall, the ODOT ITS unit scheduled a series of meetings with different stakeholder groups during late May 1999. The structure of each meeting varied slightly with the overall goal of answering a few broad questions for each group:

[1] While the California-Oregon Advanced Transportation System (COATS) Project between the California Department of Transportation (Caltrans) and ODOT has identified initial ITS deployment projects, for the purposes of this report they are not included.
[2] Where not explicitly indicated, locations where assumed based on device function and need.

Device	Region	Existing	Existing + STIP	Existing + STIP + Strategic Plan
Automatic Traffic Recorders	Region 1	26	27	29
	Region 2	26	30	46
	Region 3	26	28	31
	Region 4	23	24	26
	Region 5	26	26	29
	State Total	127	135	161
Speed Zone Monitoring Stations	Region 1	4	4	4
	Region 2	8	8	8
	Region 3	4	4	4
	Region 4	9	9	9
	Region 5	9	9	9
	State Total	34	34	34
Closed-Circuit Television (CCTV) Surveillance	Region 1	39	46	119
	Region 2	5	7	45
	Region 3	1	1	41
	Region 4	10	15	40
	Region 5	1	18	31
	State Total	56	87	276
Video Detectors	Region 1	-	-	100
	Region 2	4	5	5
	Region 4	-	1	1
	State Total	4	6	106
Road and Weather Information System (RWIS)	Region 1	6	9	14
	Region 2	4	9	24
	Region 3	1	4	24
	Region 4	8	15	37
	Region 5	1	20	29
	State Total	20	57	128
Travel Time Estimation	Region 1	-	-	80
	State Total	-	-	80
Automatic Vehicle Location (AVL)	Region 1	7	7	107
	Region 2	-	4	104
	Region 3	-	-	100
	Region 4	-	40	100
	Region 5	-	-	100
	State Total	7	51	511
Ramp Metering	Region 1	64	90	150
	Region 2	-	-	65
	Region 3	-	-	35
	State Total	64	90	250

Table 2-1: Statewide ITS Inventory Assumptions.

Device	Region	Existing	Existing + STIP	Existing + STIP + Strategic Plan
Emergency Signal Preemption	Region 1	206	206	206
	Region 2	104	104	104
	Region 3	59	59	59
	Region 4	51	51	51
	Region 5	23	23	23
	State Total	443	443	443
Transit Signal Prioritization	Region 1	17	17	17
	Region 2	-	-	100
	State Total	17	17	117
Advanced Traffic Management System	Region 1	1	1	1
	Region 2	-	-	1
	Region 3	-	-	1
	Region 4	-	-	1
	Region 5	-	-	1
	State Total	1	1	5
Callboxes	Region 3	4	4	4
	State Total	4	4	4
Cellular Call-In	Region 2	-	-	1
	State Total	-	-	1
Regional Incident Detection System	Region 1	-	1	1
	State Total	-	1	1
Intersection-Based Incident Detection System	Region 2	-	1	1
	Region 4	-	1	1
	State Total	-	2	2
Computer-Aided Dispatch	Region 2	5	5	5
	Region 3	2	2	2
	Region 4	2	2	2
	State Total	9	9	9
Incident Response Vehicles	Region 1	7	7	7
	Region 2	-	4	4
	State Total	4	-	-
Pre-planned Detour Routes	Region 1	-	-	500
	Region 2	-	-	100
	Region 3	-	-	100
	Region 4	-	-	50
	State Total	-	-	750
Hazardous Material Response	Region 2	-	-	1
	State Total	-	-	1
Alphanumeric Paging	Region 1	1	1	1
	State Total	1	1	1
Highway Travel Conditions Reporting System	Region 2	-	1	1
	State Total	-	1	1

Table 2-1: Statewide ITS Inventory Assumptions. (cont.)

Device	Region	Existing	Existing + STIP	Existing + STIP + Strategic Plan
800-number Information	Region 2	1	1	1
	State Total	1	1	1
Internet Access	Region 2	1	1	1
	State Total	1	1	1
Kiosks	Region 1	-	-	117
	Region 2	-	-	30
	Region 3	-	-	30
	Region 4	-	-	30
	Region 5	-	-	30
	State Total	-	-	237
Icy Bridge Warning CMS	Region 3	1	1	1
	State Total	1	1	1
Tunnel Lane Closure CMS	Region 1	1	1	1
	State Total	1	1	1
Radio-Controlled Snow Zone CMS	Region 4	4	4	4
	State Total	4	4	4
Telephone-Activated Snow Zone CMS	Region 5	8	8	8
	State Total	8	8	8
Oversize Vehicle Restriction CMS	Region 2	1	1	1
	State Total	1	1	1
Permanent Variable Message Signs	Region 1	12	16	32
	Region 2	5	9	9
	Region 3	2	2	2
	Region 4	1	1	1
	Region 5	5	10	18
	State Total	25	38	62
Portable Variable Message Signs	Region 1	1	1	61
	Region 2	19	19	99
	Region 3	-	-	100
	Region 4	3	5	102
	Region 5	-	-	100
	State Total	23	25	462
Highway Advisory Radio (HAR)	Region 3	1	1	1
	State Total	1	1	1
Icy Bridge Detectors	Region 1	1	1	5
	Region 2	-	-	4
	Region 3	-	-	4
	Region 4	-	-	4
	Region 5	-	-	4
	State Total	1	1	21

Table 2-1: Statewide ITS Inventory Assumptions. (cont.)

Device	Region	Existing	Existing + STIP	Existing + STIP + Strategic Plan
Oversize Load Detectors	Region 4	-	5	5
	State Total	-	5	5
Variable Speed Limit Signs	Region 1	-	-	2
	Region 2	-	-	3
	Region 3	-	-	5
	Region 4	-	-	5
	Region 5	-	-	5
	State Total	-	-	20
Queue Detection System	Region 2	1	1	1
	State Total	1	1	1
Weigh-in-Motion (WIM) Stations	Region 1	-	5	5
	Region 2	2	3	3
	Region 3	4	4	4
	Region 4	-	4	4
	Region 5	5	5	5
	State Total	11	21	21
Downhill Speed Advisory Systems	Region 2	-	-	4
	Region 3	-	1	8
	Region 4	-	-	7
	Region 5	1	1	7
	State Total	1	2	26
Fiber Optic Networks	Region 1	-	80	80
	State Total	-	80	80
Radio Communications	Region 1	4	4	4
	Region 2	5	5	5
	Region 3	2	2	2
	Region 4	2	2	2
	Region 5	-	-	2
	State Total	13	13	15
Maintenance Coordination	Region 1	-	1	1
	Region 2	-	1	1
	Region 3	-	1	1
	Region 4	-	1	1
	Region 5	-	1	1
	State Total	-	5	5

Table 2-1: Statewide ITS Inventory Assumptions. (cont.)

- What should the maintenance model look like? This question was broken up into several smaller questions to get at specific issues such as tracking, prioritization, and budgeting.

- Where do you perceive your responsibilities for ITS maintenance beginning and ending? Because ITS devices tend to cut across organizational lines in their operations and maintenance, it was important to determine how stakeholders thought lines of responsibility should fall.

- What are your top three ITS maintenance priorities?

- What would you hope for the ITS maintenance plan to accomplish?

These questions were presented in a matrix format to each stakeholder group as shown in Table 2-2. Meetings were held with eight different groups of stakeholders, as shown in Figure 2-1. Each of the stakeholder groups was selected to represent a unique perspective on ITS maintenance within ODOT.

- The ITS Executive Steering Committee is a high-level, policy-oriented committee which sets the direction for ODOT's ITS efforts. Its membership includes key leaders from several planning and operational units. The committee has many broad roles, including maintaining oversight of staff working on ITS issues, assisting with statewide coordination of ITS efforts, and setting prioritization of ITS initiatives and funding.

- The District Managers are responsible for day-to-day maintenance operations in each of ODOT's districts. Their maintenance responsibilities include not only ITS devices but also traditional highway maintenance, such as pavement and structures. They are responsible for budgeting and scheduling maintenance activities at the district level.

- The Transportation Operation Center (TOC) Managers are responsible for day-to-day operations of the state's four TOCs, which are located in Portland, Salem, Medford and Bend. The TOCs are generally "consumers" of ITS device data outputs, as these devices help the TOCs to better manage traffic congestion, report on traffic conditions, and coordinate incident response and management.

- Information Services has oversight responsibility over ITS hardware and software installations. They provide data storage for ITS databases, provide computer hardware and software support, and manage communications links and networks.

- The Regional Electricians are tasked to perform day-to-day ITS maintenance. They are generally the first line of defense for maintenance of many ITS devices, including ramp meters, variable message signs (VMS) and cameras.

- The Traffic Signals Services Unit (TSSU), based in Salem, is responsible for testing of traffic control devices as well as higher-level maintenance. If electricians are not

			Stakeholder "Clusters"					
What should the maintenance model look like?	Problem identification and verification							
	Problem reporting and assigning							
	Problem logging and tracking							
	Resource allocation: equipment, staff, training, spare parts, etc.							
	Centralized or distributed?							
	Vendor or in-house?							
	Prioritization (preventative vs repair)							
Where does your responsibility for ITS maintenance begin and end?								
What are the top three ITS maintenance priorities?		1						
		2						
		3						
What do you hope the ITS Maintenance Plan will be able to accomplish?								

Table 2-2: Questions for Stakeholder Meetings.

able to successfully resolve a problem with an ITS device, TSSU is often used as the next line of help.

- The Motor Carrier Transportation Division has statewide responsibility for transportation issues related to the motor carrier industry. They are responsible for maintaining ITS installations related to trucks, such as weigh stations with weigh-in-motion technology.

- The Transportation Data Section (TDS) is responsible for both operating and maintaining automatic traffic recorders (ATR) throughout Oregon, which are used primarily in statewide planning efforts.

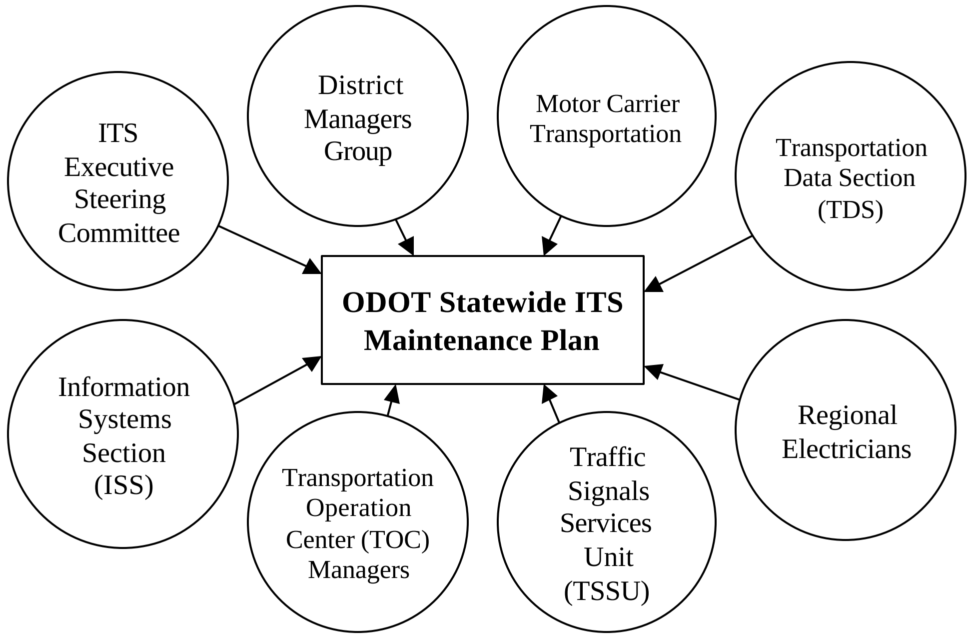

Figure 2-1: Stakeholder Groups.

A list of participants attending each of the stakeholder meetings is in Appendix A.

Several common themes emerged from these stakeholder meetings in answer to the four broad questions introduced earlier. This section will summarize the stakeholders' responses to these questions.

2.2.1 Maintenance Model

In defining existing and desired maintenance models, stakeholders were asked to consider several different aspects:

- Problem identification and verification. How are problems typically identified? How are problems normally diagnosed?
- Problem reporting and assigning. What is the process for problems to get reported and assigned to the right people?
- Problem logging and tracking. What processes exist for logging maintenance activities? How are problems tracked from identification through resolution?
- Resource allocation. What are current issues with resource allocation in terms of staffing, training, equipment and spare parts?
- Centralized or distributed. Would a centralized or distributed maintenance model work better?

- Vendor or in-house. Under what conditions should vendors be brought in to perform maintenance?

- Prioritization. How are repairs prioritized? Where does preventative maintenance rank among maintenance priorities?

2.2.1.1 Identification and Verification

For the majority of ITS devices that are currently in the field, device malfunctions are reported either through individuals reporting problems or through querying processes run by ODOT staff. When "pull technology" such as this is used as the primary method of problem identification, problems will be remedied only as quickly as they are made known. Relying on "pull technology" to report problems is effective in a sense, then, since it allows ODOT to focus its maintenance efforts on devices that are being used regularly by the public or by ODOT operators.

There are a couple of problems with "pull technology" however, which were brought out in the stakeholder meetings.

- Devices located in rural areas, such as some closed-circuit television (CCTV) cameras and VMS, may be left inoperable for long periods of time unless a problem is reported. These locations may be strategically important for safety and/or liability reasons. Consequently, ODOT will not be getting the maximum potential use out of its ITS investment.

- Pull technology requires additional effort by maintenance staff in terms of querying existing devices. Significant time savings could result if expert systems were used which allowed devices to initiate reports whenever a malfunction occurred.

Some devices, such as road and weather information systems (RWIS) stations, have the capability to report to an operator through e-mail that there is a device malfunction. Some devices that already have such self-diagnostic capabilities, such as ramp meters and traffic signal controllers, are not being presently utilized. Stakeholders agreed that future systems would likely need a greater degree of self-diagnosing capability.

Problem verification or troubleshooting is a concern for many ITS devices, due to both a lack of adequate training for maintenance personnel and a lack of 24-hour, 7-day support.

2.2.1.2 Reporting and Assigning

The stakeholder meetings revealed that there are varying practices for the reporting and assigning of maintenance needs, with there being no statewide reporting model. There are instances of reporting and assigning practices that have been established and are adhered to with good results. TDS, for example, is able to maintain over 90 percent of its ATRs working at any given time due to an established problem identification and assignment process. The Motor Carrier Transportation Division, through the use of contracting, has a process for automatically reporting and assigning maintenance needs so that they will be resolved in a predetermined time. For many other devices, however, there is no similar procedure. It was learned that there is generally no single point of contact for ITS maintenance needs and no common procedure for assigning the repairs to the appropriate individual.

In assigning ITS maintenance, one problem that was brought up during several meetings was the lack of training to handle ITS maintenance. Traditional channels that would be used for maintenance of other systems within ODOT are currently not adequate for handling current maintenance needs. Information Services, for example, would traditionally be a point of contact for software and hardware maintenance issues related to ITS devices. However, their desktop support is trained primarily on traditional desktop applications rather than very specific, localized software packages associated with individual devices. Electricians would normally be the first line for electrical devices in the field, but in many cases lack the training to be able to properly diagnose and remedy malfunctioning ITS field devices.

Another concern raised was the lack of consistent 24-hour, 7-day support for ITS devices. For many deployments, it is critical that the devices be operational on a continual basis, even during weekends and overnight. However, many support services within ODOT are not currently equipped to be able to provide comparable support. In the desire to expedite repairs, operators and managers have learned to do some repair work outside of normal channels in order to improve operations of the transportation system for both operators and users.

2.2.1.3 Logging and Tracking

When stakeholders were asked about the logging and tracking of maintenance on ITS devices, it was discovered that there is no common form of logging and tracking problems; it varies by groups and regions. TSSU, for example, has established a paper logging system, which is later entered into a central computerized database, which tracks maintenance performed on all state-maintained traffic signals. TDS uses a similar system for tracking the maintenance history of its ATR equipment. These databases, however, are still primarily paper-based and are limited to only a few types of ITS devices. For most devices, little or no tracking is done. In addition, these databases are typically not accessible across different ODOT units, which many stakeholders cited as a problem.

Many stakeholders expressed a desire to see a common automated means of logging and tracking maintenance that could be commonly accessed between stakeholders. It was hoped that such a system could be used to track costs by specific field devices, which could help to develop better estimates of budgeting based on features.

In reviewing this process of logging and tracking, it was found in summary that there is no collective oversight for problem management, hand-offs, tracking and coordination.

2.2.1.4 Resource Allocation

The common perception from stakeholders is that ODOT is moderately to severely understaffed to handle current ITS maintenance needs, depending on location and activity. District managers, for example, reported that ITS devices have been added to their district's maintenance needs without the additional resources to maintain them. Consequently, the focus is primarily on reactive maintenance or "putting out fires" rather than proactive or preventative maintenance. Logging and tracking activities are also underemphasized.

Moreover, in some instances, such as the more rural regions, there is a single individual who has broad-based maintenance knowledge and institutional memory. In the event that these key individuals leave the organization, all the institutional memory would go with them, leaving broad sections of the ITS infrastructure without anyone who knows how to maintain or even operate them.

As was discussed in how problems are assigned, there was a concern that staffing decisions did not reflect the need for a 24-hour, 7-day operational focus. Personnel qualified to do maintenance, in many cases, still work traditional weekday, daytime hours, which may not be adequate to support the operations of the TOCs, which operate on a 24-hour, 7-day basis.

There appears to be a universal need for improved training for maintenance personnel. Devices are often deployed without adequate training of the staff who would maintain them, and without sufficient documentation for basic troubleshooting tasks. Stakeholders felt that training needs should be included in both the design specification and procurement processes. There was also a desire for cross-functional training that would enable maintenance staff to be more effective in troubleshooting and isolating faults in ITS devices, even if they were not ultimately responsible for performing the maintenance item in question.

In addition to concerns about general understaffing, it was suggested that existing staffing could be more effectively utilized if there were greater standardization of ITS devices. Standardization has been introduced in other departments of transportation through tight specification processes and standard vendor or parts lists for purchasing. Increased standardization of devices improves the familiarity of maintenance staff with their operations, reducing the average time it takes to repair devices.

Standardization would have the added benefit of reducing the amount of spare parts needing to be kept on-hand to respond to repairs in a timely fashion. One success story with standardization is TSSU, which has had oversight over the Type 170 traffic signal controller becoming the statewide standard for signal control. Prior to this, field technicians had to maintain over a dozen different types of controllers in their central Salem warehouse; now they only need to keep a handful in stock, greatly saving in both space and the cost of special orders.

It was perceived that improved planning would help to improve the operations and maintenance of ITS installations. First, changes should be considered to the procurement process that would allow the procurement decision to reflect life cycle costs rather than just initial capital costs. Often it is found that low initial item cost is associated with higher maintenance cost and shorter operational life; life cycle cost analysis data could be used to create a “standard device list” from which items for purchase could be selected. There may be devices where a scaleable standard design has been found that will work well with all the regions. This would perhaps result in higher capital costs than a non-standardized device, but would have lower maintenance costs that could result in cost savings over the life of the device. Until these changes are implemented, tighter specifications could be drafted in order to ensure standardization is obtained. Second, some parts of the state, specifically Regions 2 and 3, expressed interest in having a strategic or implementation plan for ITS devices. A greater understanding of how these devices are to integrate into the broader transportation system to meet user needs may help to improve how resources are allocated to maintain the devices.

2.2.1.5 Centralized vs. Distributed System

Stakeholders were also asked their perspectives on resource allocation in terms of whether they thought resources would be better to be centralized statewide or distributed regionally. The responses across groups reflect the different priorities and responsibilities each group has for ITS maintenance.

- The electricians wished to have a centralized budget to handle major ITS repairs. They were concerned about the potential high cost of repairing an ITS device that has a catastrophic failure.
- The TOC managers preferred to have local ITS maintenance budgets, so they could have greater flexibility in addressing their needs, but a centralized budget for larger capital expenditures.
- The Motor Carrier Transportation Division perceives itself as having an independent, centralized maintenance model through contracting. They budget $1.2 million per year which covers all of their ITS maintenance needs statewide.
- Information Services preferred a certain degree of centralization in order to ensure standardization of equipment.
- TDS suggested that there should be a centralized budget for major parts, but that technician time should be charged on regional budgets as utilized.
- TSSU favored a tiered approach, with centralized core capabilities and distributed trouble shooting and diagnostics. They believe that the budgeting should follow a similar structure.

Several groups suggested that a good model for centralization would be the state's fleet management model.

2.2.1.6 Vendor vs. In-house

Stakeholders were asked to identify which factors do or should determine whether contractors are utilized to perform maintenance on ITS devices. Responses indicated that there were five primary factors that would influence this decision.

1. In-house capability is generally desired for mission-critical business, such as safety. Wherever expedited response time is an important concern, stakeholders expressed reluctance on utilizing contractors.
2. Contractors would be preferred if significant technical ability is required or if there is a deficiency in training. Some ITS devices may require significant amounts of training or higher education to be able to properly maintain. It may be more cost-effective in these cases to use contractors. In other cases, the training required might not be that substantial, but maintenance personnel do not have adequate time to take

training classes. Contractors could be used for stopgap maintenance until in-house support could get up to speed.

3. Support service may not be available. Contract maintenance may be desirable in some rural areas, where limited applications of ITS devices do not warrant significant amounts of training. However, because of the remote location of these devices with respect to contractor offices, companies may not be willing to contract to maintain these devices, or they may demand a premium fee to do so.

4. Contractors may be more appropriate for non-standardized equipment. Stakeholders from several groups suggested that a tiered approach should be used in maintenance of ITS devices. Each device has a testing or early deployment stage when small amounts of different technologies are being tested at different locations. In this stage, it is probably not economical to have in-house training for each of these different types of devices. As equipment becomes more standardized, training of maintenance personnel could begin to focus on one or two specific models of each device, making it more effective to handle maintenance in-house.

5. There may be inadequate numbers of staff to handle maintenance. Understaffing in many districts and divisions, due to legislative caps on total ODOT staffing levels, may force them to outsource maintenance, as opposed to the alternative of having devices which either operate inadequately (CCTV cameras which cannot pan or tilt, for example) or remain inoperative altogether.

The different factors involved in the decision whether to use contractors or in-house resources for ITS maintenance suggested that there should be some flexibility in how a maintenance plan addresses this part of the maintenance model.

2.2.1.7 Prioritization

There was a common theme from many of the groups that preventative maintenance was difficult to perform due to a lack of continuing resources. There were a couple of exceptions, such as TDS, which performs annual inspections of each of its ATR installations and does some routine replacement of parts. Given the choice between performing preventative maintenance or repair maintenance, stakeholders always favored performing repair maintenance.

Given constraints on resources, however, there is the question as to how repairs should be prioritized. There was no unanimous consensus on which factors are the overriding factors in determining what gets fixed first, but several factors were brought up repeatedly as playing into the prioritization decision.

- Safety. According to its mission statement, ODOT's mission is "to provide *safe* and effective transportation systems that support economic opportunity and livable communities for Oregonians." (1) Stakeholders expressed unanimous consent that the safety of the driving public was a dominant concern in deciding how device repair is prioritized. Stakeholders had different viewpoints, however, based on their own operational experience, of which ITS devices were most critical for safety.

- Traffic control devices. Urban TOC managers perceived that traffic control devices would be a top maintenance priority, because successful traffic control has a clear relationship to safety in congested urban roadway networks.

- Liability. Many devices need to be properly maintained for legislative and liability reasons. ATRs, for example, are required to be operational as a part of federal legislation, so TDS has a preventative maintenance program as well as a reporting and tracking system to help ensure compliance.

- Advisory or information devices. These devices may be necessary to report road closures or hazardous conditions to motorists in order that they may take appropriate actions. If these devices are inoperative, especially in more rural areas during hazardous weather conditions, the safety consequences can be severe.

- Public perception / level of service. The use of ITS devices is increasing the visibility of ODOT to the public. When ITS devices are operational, motorists appreciate the additional information and have commended stakeholders through various means to continue similar efforts. However, the public will likely be disposed against continued investment in new or expanded ITS deployments if it sees that efforts are not made to maintain devices once they are deployed. Stakeholders expressed an interest in prioritizing maintenance on devices that the public is more apt to notice.

- Geography. One clear finding out of meeting with the different stakeholder groups is that there is no obvious scheme that could be implemented statewide dictating how repairs should be prioritized. Operators and managers desired to have some local flexibility to be able to prioritize maintenance needs according to user needs.

2.2.2 Perceived Responsibilities

Stakeholders were asked to identify where they perceived their responsibilities beginning and ending for ITS maintenance. It was intended that this question would be a diagnostic tool, identifying areas of either overlapping responsibility between different groups, or areas of lapsed responsibility, with no one believing they were responsible for maintenance. As shown in Table 2-3, there seems to be overlap in perceived maintenance responsibilities between stakeholder groups. This chart highlights several issues when it comes to responsibility for ITS maintenance.

There are differences of opinion between repair and oversight responsibility, or between the perspective of maintenance providers and maintenance consumers. TOC managers, Information Services and TSSU each perceived that they had essentially “end-to-end” responsibility for maintaining certain ITS devices, but that means different things to each group. The TOC managers perceive themselves as primarily users of the devices, so it is their ultimate responsibility to ensure that the devices are working satisfactorily, although they may not necessarily make physical repairs to fix a device. Information Services believed their responsibility as a maintenance provider was to provide support at every level to ensure that the device users would be satisfied. TSSU perceived that they had responsibility over the electromechanical aspects of each of the devices, and have worked on modems and communications support for some devices previously. These conflicting understandings of

X - Active responsibility C - Contracted responsibility Stakeholders	Sensors	Communications	Field Controller / Processor	Software	Center Sub-System	Information Delivery
Regional Electricians	X	X	X			X
Transportation Data Section	X	X	X			
TOC Managers	X	X	X	X	X	X
Information Services		X	X	X	X	X
Motor Carrier Transportation Division	C	C	C	C	C	C
Traffic Signals Services Unit	X	X	X	X		

Table 2-3: Perceived ITS Maintenance Responsibilities.

responsibility illustrate that there are no clear guidelines for delineation of responsibilities. Most stakeholder groups perceive they are responsible for several elements of the system.

One important point to emphasize is that the lines of perceived responsibility vary by region. In rural areas, where it may be more difficult to obtain appropriate support from Information Services, managers perceive they have a greater repair responsibility over even the computer and communications elements.

2.2.3 Top ITS Maintenance Priorities

Stakeholders were asked, without referring to any pre-determined list of factors, to prioritize their top concerns for ITS maintenance. The most common answers, in no particular order, are as follows:

- Implement and increase consistent training and technical support. Stakeholders were concerned about gaps in training and support, especially in order to sustain 24-hour, 7-day operations.

- Address staffing needs. Stakeholders were concerned not only with the number of staff that could be dispatched to repair problems, but also their capabilities. It was believed that staffing and training levels ought to keep pace with the deployment of devices.

- Introduce standardization of ITS devices, systems and software. Stakeholders perceived standardization as having many benefits to ODOT, such as reducing spare parts inventories and staffing needs, improving the ability to troubleshoot and provide technical support, and reducing long-term maintenance costs. Successful standardization, it was believed, was going to depend upon determining who would be responsible for developing standard specifications, identifying standards which could be scaleable for different regions and needs, and enforcing standards to ensure that they are heeded in procurement decisions.

- Clearly define processes, procedures and budgets. The absence of logging and tracking of ITS maintenance, the absence of a single point of contact for device failure, and a lack of features-based budgeting for ITS devices were among many concerns cited in this area.

- Provide a clarification of roles and responsibilities for ITS maintenance. Table 2-3 indicated the overlapping and misunderstood roles and responsibilities that different stakeholders have. Stakeholders desired that this inefficiency should be resolved.

- Establish prioritization to accomplish tasks. Given scarce resources, there was a desire for a more universal understanding of what is most important for ITS maintenance. Stakeholders at the operations level are looking for increased guidance in this area.

- Create strategic implementation plans. There was a perception in some more rural areas that improved strategic planning of ITS devices would help to better define maintenance needs and strategies.

- Introduce redundancy in personnel, equipment and knowledge. Better logging and tracking of device maintenance history, improved training, and increased dissemination of knowledge among staff were commonly expressed goals. People who by their unique knowledge and skills could present a "single point of failure" desired that others would have the time to increase their respective knowledge and skills as well.

- Focus on pre-deployment testing of equipment. Devices deployed without proper testing can yield significant maintenance headaches in the future. Stakeholders expressed the desire to see devices tested before they were put into the field to reduce the frequency and severity of failure.

2.2.4 Desired Plan Accomplishments

The ITS maintenance plan, because it will cut across so many jurisdictions, requires a significant degree of consensus from the various stakeholder groups if it is to be effective. Therefore, as a final question, stakeholders were asked to define what they desired the plan to accomplish. In addition to the priorities discussed in the last section, four major points came out:

- The plan should serve as a foundation for addressing all issues and regions. Stakeholders wanted this to be a comprehensive yet simple plan for addressing ITS maintenance throughout the state. Because of the many differences between regions that have been discussed, stakeholders felt that the plan should be flexible to regional needs.

- The plan should develop a process for new technology implementation. Stakeholders desired that the plan should not be static, limiting itself only to those devices that are currently deployed or included in the strategic plan. The plan should recommend procurement and deployment strategies for new devices and technologies which reflects upcoming maintenance needs, and delineate a process for determining how maintenance for these devices will be funded and performed.

- The plan should raise awareness of staffing, training, maintenance, and standardization needs. Stakeholders were appreciative of the chance to offer input into the maintenance plan with the hope that it will help them to do their job better. They hoped, therefore, that the plan would help to highlight deficiencies in the existing system in order to provide for improved allocation of resources, especially as additional ITS devices continue to be deployed.

- The plan should clearly define organizational responsibilities. Stakeholders desired greater clarity in the boundary lines for not only their unit's responsibilities, but for other units as well. It was hoped that any organizational responsibilities presented in the plan would be flexible enough to adapt to changes in technology in the future.

The key findings of the stakeholder meetings are summarized in Table 2-4.

2.3 Literature Review

One early task in this project was to research and benchmark other maintenance plans from within and outside of the transportation industry. The first aspect of this research effort focused specifically on maintenance plans developed by other transportation agencies. It was learned that, in general, there are few published plans detailing maintenance of Intelligent Transportation Systems relative to the number of devices employed nationwide. Most plans that have been developed for ITS to date are strategic plans relating to deployment. These plans often have very broad estimates of maintenance costs, with little or no consideration of organizational structure, prioritization, tracking, maintenance procedures and other issues that ODOT has identified as being of critical importance.

Some plans were identified that examine maintenance in greater detail. Table 2-5 provides a detailed tabular summary of each of these maintenance plans[3]. In reviewing these plans, several key points may be made.

- Several metropolitan areas have developed models for maintenance plans. However, during the literature search, however, no statewide maintenance plan was identified. This suggests that ODOT is at the forefront of transportation agencies by attempting to document ITS maintenance needs on a statewide basis.

- Some, but not all, maintenance plans make a connection between device deployment and the resources needed to maintain them. During meetings with stakeholders, it was

[3] More detail on each of these maintenance plans is provided in Appendix B.

Identification and Verification	• Problems traditionally identified via individuals reporting or querying ("pull technology") • Some effective self-diagnosing systems are in use; some available but not presently being utilized (e.g. signal controllers & ramp meters) • Future systems will need greater self-diagnosing capability (e.g. RWIS) • Lack of 24 hour / 7 day support common • Rural applications more challenging to detect than urban
Reporting and Assigning	• No statewide reporting model • No single point of contact • No common procedure (i.e. one-stop shopping) • Information Services Help Desk is trained for traditional desktop PC applications, not ITS applications • Lack of consistent 24 hour / 7 day support
Logging and tracking	• No common form of logging and tracking problems; it varies by groups and regions • Logging and tracking is generally not done, or is done on paper. No common automated means is presently used • No shared logging/tracking database between stakeholders • No collective oversight for problem management, hand-off, tracking and coordination • Desire by stakeholders to track all costs by device (e.g. feature)
Resource Allocation	• Levels of standardization in part determines required levels of staffing, spare parts • Moderate to severe understaffing, depending on location and activity • In some severe cases there is a single individual (single point failure) for maintenance and institutional memory • Current focus is on reactive vs. proactive maintenance; ("fire drills") • There is a need for 24 hour / 7 day focus • Need to consider life-cycle costing (low bid item may mean higher maintenance costs) • Strategic / implementation plans needed (Regions 2 and 3) • Training is universally needed; should be included in specifications and purchasing • Cross-functional training needed for effective fault isolation and troubleshooting

Centralized vs. Distributed System	• Diverse perspectives depending upon group
	  • Electricians: desire centralized budgeting to handle major ITS repairs.
	  • TOC Managers: prefer local ITS maintenance budgets.
	  • Motor Carrier: implementing independent, centralized model through contracting
	  • Information Services: centralization preferred for control of standardized equipment
	  • TDS: suggest central budget for major parts, but charge technician time on regional budgets as utilized.
	  • TSSU: tiered approach – centralized core capabilities with distributed trouble shooting and diagnostics, with similar budgeting.
	• Several groups suggested investigate fleet management model

Table 2-4: Summary of Stakeholder Meetings.

Vendor vs. In-house	• Depends upon several factors
	  • In-house capability generally desired for mission-critical business (e.g. safety)
	  • Technical ability required or training deficiency (vendor)
	  • Depends on availability of support service and willingness to pay?
	  • Contractor more appropriate for non-standardized equipment (tiered approach)
	  • Vendors may fill in gaps left by understaffing

Prioritization	• Diversity of opinion on prioritization, depending upon many factors:
	  • Safety
	  • Traffic control
	  • Liability
	  • Advisory / information devices
	  • Public perception / level of service
	  • Geography

Perceived Responsibilities	• No clear guidelines for delineation of responsibilities • Most stakeholder groups claim responsibility for several elements of the system • Differences in opinion between repair vs. oversight responsibility • There is a difference in perspective of maintenance providers (e.g. Information Services) vs. maintenance consumers (e.g. TOCs) • Boundaries vary by region (rural vs. urban)
Top ITS Maintenance Priorities	• Desire increased and consistent training and technical support (24 hour / 7 day) • Address staffing needs • Implement standardization of ITS devices, systems and software • Clearly define processes, procedures and budgets • Provide a clarification of roles • Establish prioritization to accomplish task • Create strategic implementation plan • Redundancy in personnel, equipment and knowledge • Focus on pre-deployment testing
Desired Plan Accomplishments	• Foundation for addressing all issues and regions • Develop process for new technology implementation • Raise awareness of staffing, training, maintenance, and standardization needs • Define organizational responsibilities

Table 2-4: Summary of Stakeholder Meetings. (cont.)

Categories	Metropolitan Area Plans				State Plans	
	Caltrans District 7 (6)	**Washington St. DOT SC&DI / Seattle (7)**	**Minnesota DOT I-494 ICTM (5)**	**National ITS Architecture (8)**	**Arizona DOT PECOS (9)**	**Texas DOT (10)**
Maintenance Model						
How are problems identified?	1. System operators report system errors to system administrator 2. Reported by system users through cellular phone 3. Network Management System will automatically detect Transportation Operations System communications	Flow engineer monitors for malfunctions	Problems detected by system software and reviewed daily by system operator	Not provided	Not provided	Not provided
How are problems verified?	Detected problems are verified by appropriate support group: • Field Support Engineers • System Engineers • TMC User/ Operator • Technicians • Contract Staff	Radio dispatch assigns the appropriate maintenance personnel to verify the problem and make repairs. The radio dispatcher is given permission by the on-call supervisor	Appropriate agency notified by operator	Not provided	Not provided	Not provided
What is the repair process?	A support group is dispatched (based on prioritization) to repair the equipment.	Maintenance personnel dispatched by SC&DI or FLOW engineer	Notified agency dispatches a technician to repair failed system	Not provided	Not provided	Not provided
What is the logging and tracking procedure?	All repair times and equipment recorded by "trouble-ticket"	Fundamental tracking procedure provided: 1. Reporting the problem (usually by operators) 2. Verification and repair 3. Logging activities through Access database for forecasting purposes	1. Repair activities are logged along with future repair requirements 2. Log is faxed back to operator for tracking of future activities 3. Final log kept on file	Not provided	Problems detected and recorded on PECOS computer system. Inventory, labor, equipment, material recorded via dial-up link for forecasting purposes	Not provided

Table 2-5: Comparison of ITS Maintenance Plans.

	Metropolitan Area Plans				State Plans	
Categories	**Caltrans District 7 (6)**	**Washington St. DOT SC&DI / Seattle (7)**	**Minnesota DOT I-494 ICTM (5)**	**National ITS Architecture (8)**	**Arizona DOT PECOS (9)**	**Texas DOT (10)**
Maintenance Model (continued)						
How are roles and responsibilities defined?	The support staff are listed above. All roles and responsibilities of staff are described within the document.	Responsible parties are as follows: 1. Engineers (Freeway Operators, SC&DI Operators, Flow, Software) 2. Flow Operators 3. Computer Programmers 4. Traffic System Operations Specialists	Based on agency or jurisdiction Agency is responsible for equipment within its jurisdiction. Roles of ICTM staff described, and existing staff for each jurisdiction briefly described.	Not provided	Not provided	Not provided
Repair Prioritization						
What factors determine how repairs are prioritized?	Tasks prioritized on basis of: • Public Safety • Traffic Service • Preservation of facility/operational integrity • Appearance	Response times based on repair time and importance of the equipment in SC&DI system	ITS elements prioritized and activities identified as Critical or Non-critical based on overall system importance Minimal repairs made on low priority equipment until time allows further repairs	Not provided	Not provided	Not provided
Resource Needs						
How are needs estimated?	Labor requirements and maintenance support costs predicted for 10 yr. period Maintenance divided into scheduled and unscheduled tasks Assumed O&M costs stabilize after five years	Maintenance divided into preventative and repair of malfunction categories	Maintenance separated into preventative, critical, and non-critical maintenance tasks based on manufacturer suggestion Limited tasks listed	Maintenance divided into recurring and non-recurring tasks per ITS element tabulated Maintenance provided for various geographical regions	Based on previous year's maintenance costs	Maintenance costs provided for system to maintain system at "tolerable" levels
How are changing needs addressed over time?	First 5 years of plan costs are assumed to rise with additional devices	Costs are expected to rise with preventative maintenance plan	Costs expected to rise following operational test and warranty expiration	Needs assessed for 1996	Costs expected to rise with additional deployment and device replacement	Recommends aggressive upgrading and replacement, but doesn't provide costs

Table 2-5: Comparison of ITS Maintenance Plans. (cont.)

	Metropolitan Area Plans				State Plans	
Categories	**Caltrans District 7 (6)**	**Washington St. DOT SC&DI / Seattle (7)**	**Minnesota DOT I-494 ICTM (5)**	**National ITS Architecture (8)**	**Arizona DOT PECOS (9)**	**Texas DOT (10)**
Resource Needs (continued)						
How does the plan address preventative maintenance?	Specific requirements listed for each piece of equipment	Preventative maintenance performed at same time as repairs Suggested preventative maintenance tasks are provided	Preventative maintenance guidelines not provided but recommended	No schedule is provided Preventative maintenance is included in recurring operations and maintenance costs	No schedule is provided Preventative maintenance is a separate cost item	No schedule is provided Preventative and repair maintenance are combined in cost analysis
Resource Availability						
What are staffing levels?	Person-hours required for maintenance tasks provided	Staffing levels provided, but relationship to maintenance unclear	Person-hour requirements listed to perform tasks	Not provided	Staffing requirements listed in terms of man-hours per equipment	Estimated cost per employee provided
How are staffing levels determined?	Contract support provided for man-power limitations, and specialized sub-systems	Maintenance training for software and equipment	Outside support used for expensive-to-stock equipment	Not provided	Not provided	Not provided
Budgeting						
For what years is a budget developed?	Budget provided 1996-2006	Budget provided 1996 All improvements to be online by 2000	Budget provided 1995	O&M costs provided per system element 1996	Budget provided 1998-2012 Costs provided for next fiscal year based on present year & assumptions	O&M costs provided per system element 1996
How much money is predicted for maintenance?	Funding range $2,941,587 -$6,220,989 per year for operations and maintenance	Maintenance Costs $115,000 per month or $1,380,000 per year	Replacements and services $90,955 annually	Variable budget, depending upon number of devices	Funding range $2,871,376 - $11,177,513 per year for operations and maintenance (includes replacement costs)	Variable budget, depending upon number of devices
What factors determine budget levels?	Quantity of equipment Cost (spare parts, training, tools, test equipment) Person-years to perform tasks	Determined by parts, labor, equipment Personnel costs determined by average hourly income. Final costs determined for maintenance costs, personnel costs, and power, phone, & vehicle costs	Maintenance costs provided for a fully operational system along with person-hour requirements Cost of maintenance based on manufacturer reliability predictions and assumptions made in analysis	Operations and maintenance costs provided for each geographical region based on individual equipment requirements and quantity Tasks and staffing requirements combined in cost analysis.	Preventative (labor, equipment, materials, man-hours) Demand (labor, equipment, materials, man-hours) Replacement Operations	Costs estimates provided per element on a per unit basis. Maintenance (both preventative & repair tasks) Operations

Table 2-5: Comparison of ITS Maintenance Plans. (cont.)

made clear by regional and district maintenance staff that the lack of such a linkage now is hampering current maintenance efforts. ODOT should, therefore, seek to develop such a linkage in its maintenance planning.

- Most maintenance models, except the Integrated Corridor Traffic Management (ICTM) project in Minnesota (6), have been developed for a single, centralized organization. While several organizations were involved in that ITS deployment, however, they were concentrated in a relatively small geographic area. Because ITS technology extends across several ODOT business units, ODOT's maintenance plan will need to have a maintenance model that provides for clear coordination of resources across different units.

- Preventative maintenance is acknowledged as critical to successful ITS maintenance. However, due to a shortage of resources, preventative maintenance tasks are often performed concurrently with repair maintenance tasks.

- Budgeting is normally a major, if not the primary, emphasis in maintenance plans. This is also true for ODOT's maintenance plan, which has as its final step the development of a comprehensive ITS maintenance budget.

The second part of the benchmarking effort focused on making contacts with the private sector. Many companies were contacted in an effort to compile data on representative maintenance plans and procedures from private industry. Company selection was intentionally limited to corporations with far-flung networks of devices similar in scope to a DOT-administered statewide ITS network. An effort was made to focus on companies that are in the midst of a technology leap from traditional infrastructure to more advanced technology systems and communications such as fiber optic communications. Companies contacted included:

- large and small telecommunications companies, such as MCI, AT&T, Bell Canada, Bend Cable, and U.S. West;
- power companies, including Pacific Gas & Electric and Montana Power;
- ITS contractors, such as 3M and International Road Dynamics; and
- many other suppliers of ITS-related components.

Additionally, organizations such as Access ITS, ITS America, the Society of Automotive Engineers, and government sources like the Federal Highway Administration were queried for contact information.

The investigation into private industry plans was less fruitful than the public maintenance planning documentation search, with regards to obtaining actual printed plans. Many working contacts were made with various private industry representatives, but little hard data was forthcoming. Reasons for the lack of success in obtaining plans include corporate guarding of "proprietary" data, lack of private industry incentive to respond to requests for information from a third party, inability to contact and interview busy corporate executives having authority to divulge planning documentation, and simply a lack of any available corporate planning documents.

Despite the lack of specific private industry maintenance planning documentation, some generalizations can be drawn regarding private industry implementation of new technology.

- When considering a new system or component involving advances in technology, a "test bed" approach is typically used to proof items prior to general implementation. This test stage helps determine whether the sensors and other intelligent systems can improve quality of service and also what maintenance and repair equipment and procedures would be needed for implementation.

- Some companies do in-house environmental testing in addition to service-based tests, to help determine life cycle costs and component reliability. Others use vendor data and warranties to supplement in-service testing for selection of components that will become the new standard. In any case, there is typically a service-based trial period prior to system-wide implementation of next-generation hardware.

- More expert systems, using artificial intelligence, are generally desired; testing is planned or under way to determine effectiveness of selected devices and systems. This is being driven by cost and manpower limitations and also by the availability of self-diagnostic capabilities in newer devices and systems.

- Regarding planning and prioritization of maintenance activities, it is currently based on human interpretation and intervention at some state of the process. One source from TCI, regarding the means of prioritizing maintenance activities, said, "His name is Bob!" In other words, an active human presence in the maintenance loop is required to correctly process diverse inputs and to determine a logical and effective course of action. This comment also points to the flexibility needed when processing and prioritizing maintenance activities. Software and hardware advances are helping to limit involvement but a human presence is still mandatory in the decision loop.

- Federal and state organizations may be ahead of many private industries in development of a comprehensive maintenance plan for this type of technology. The private sector's integration of new technology is a sequence of discovery, development, testing and implementation in order to keep a competitive advantage. The creation of a long-term maintenance plan seems in some cases to be a "luxury" that many private companies do not pursue. The philosophy differences between profit-driven private entities opposed to service-driven government agencies should be recognized.

2.4 Summary

From the stakeholder meetings and a review of public and private sector maintenance plans, the following observations maybe made.

- There is consensus at ODOT at many levels that there is a clear need for a maintenance plan.

- The scope of this project reflects the desires of ODOT stakeholders, indicating that this plan should be at least a useful starting point for ODOT's ITS maintenance.
- Plans from other transportation agencies offer some guidance in developing a plan that will meet ODOT's needs, but are often of smaller geographic scale and scope.