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**ABSTRACT**

Following the completion of the I-15 Design Build Project in preparation for the 2002 Salt Lake City Winter Olympic Games, the State of Utah Department of Transportation (UDOT) began implementing a comprehensive Strategic Asset Management System (AMS).

The Strategic AMS currently includes the analysis of the pavement, structures, safety, mobility and maintenance assets and enables UDOT to perform a traditional "silo" or "stovepipe" analysis as well as a cross asset analysis and optimization using many different objective functions.

This paper will address the technical and institutional aspects of the integration of the UDOT Pavement Management System (PMS) into the UDOT AMS and discuss the role of the PMS and the AMS in asset management at the strategic, tactical and operational levels within UDOT. It will also present the UDOT Planning Model, which describes the integration of the asset management systems at the strategic, tactical and operational levels and present the UDOT Project Harmonization approach to planning.

**INTRODUCTION**

In the fall of 2002 UDOT contacted Deighton Associates Limited (Deighton) to begin preliminary investigations into experience and capabilities in the area of Asset Management and the Deighton asset management analysis software called dTIMS CT. (1)

Those initial investigations and consultations resulted in a multi year / multi phase Strategic Highway Transportation Asset Management Implementation project within UDOT that continued to change and evolve asset management at UDOT. The project was split into a number of phases, which allowed UDOT to approach the implementation of asset management and the implementation of an asset management system using an incremental development methodology over a number of years. Initial efforts concentrated on the implementation of asset management within UDOT from an organization perspective while later phases concentrated on the implementation of an asset management system allowing for cross asset analysis and optimization across funding groups (pavement, bridge, safety, maintenance and mobility).

The project since 2002 has contributed significantly to asset management within UDOT and has resulted in many successful efforts to integrate and streamline asset management planning at UDOT. Some of the project highlights include the following accomplishments:

- **Establishment of the Transportation Asset Management Committee (TRANSMAT)**
  Comprised of UDOT senior leaders, members from the Asset Management Team and the Asset Groups. TRANSMAT is responsible for overseeing and approving asset management activities and initiatives within UDOT. TRANSMAT is ultimately responsible for the transportation service that UDOT provides and is responsible for ensuring that people, plans and processes are put in place to meet the goals and objectives that they set for the transportation system and UDOT.
- **Establishment of the Asset Management Team (AMT)**
  Established the AMT under the direction of the Director for Asset Management and created the Asset Management Engineer's position.
- **Development of the Asset Management Strategic Plan**
  Completed the Asset Management Strategic Plan outlining the strategic goals and objectives for incremental improvements to UDOT's asset management program throughout the department.
- **Development of the Asset Management Implementation Plan**
  Completed the Asset Management Implementation Plan outlining the resources and tasks necessary to meet the goals and objectives outlined within the Asset Management Strategic Plan.
- **Completed Organizational Changes to facilitate more efficient management**
  Reorganized the pavement asset group section under the direction of asset management to more effectively streamline asset management operations at the strategic and tactical levels.

- **Developed the UDOT Asset Management Strategic Planning Model**
  Developed the Asset Management Strategic Planning model to serve as a guide to developing project recommendations to include in UDOT's Long Range Plan.

- **Development of the Asset Management Database**
  The Asset Management Database was developed and implemented to facilitate asset group and cross asset analysis and optimization.

- **Development of the Asset Management Strategic Analysis**
  Configured the AMS to perform a "stove pipe" type analysis on five different asset groups (pavements, structures, safety, maintenance and mobility) and an initial prototypical cross asset analysis and optimization runs for demonstration purposes and investigation by UDOT.

- **Completed Development of a Harmonized set of Project Recommendations for the Long Range Plan**
  Facilitated the development of the harmonized project recommendations for inclusion in the Systems Preservation Plan and the UDOT Long Range Plan. The harmonization team included members from Deighton, AMT and UDOT Regions.

The remaining sections of the paper will present and discuss pavement management within UDOT, asset management within UDOT and the integration of asset group management systems (pavement, bridge, safety, maintenance and mobility) into the UDOT AMS. Prior to discussing the pavement and asset management implementations though, it is necessary to put those implementations into perspective by first presenting the vision of UDOT which is used to guide all of its business operations.

## UDOT'S MISSION AND VISION FOR THE FUTURE

In order to guide UDOT in its planning, programming and operation of the transportation network, UDOT identified the following priorities commonly known as the UDOT Final Four.

**1) Take Care of what we have**
In light of ever increasing construction costs and increased travel demand, UDOT believes that system preservation comes before system expansion. The department and its employees are committed to the philosophy that "Good roads cost less." Proactively applying well-timed treatments and other technologies to pavements can actually extend their lifetime. Similarly, routine inspections and maintenance activities on bridges are far more cost effective than replacing structures that are allowed to deteriorate. (2)

**2) Make the system work better**
Proactively managing the transportation system, through access management, traffic signal coordination, ramp meters and incident management teams will help to optimize the system. Express lanes, reversible lanes and carpool lanes are other system management techniques the department will explore in order to gain more capacity out of the existing system. (2)

**3) Improve safety**
UDOT is committed to increasing the safe travel across the UDOT network by implementing innovative safety programs and identifying safety improvement locations. By implementing innovative safety programs and identifying safety improvement locations, the department can reduce the number of traffic fatalities. Partnerships forged with law enforcement agencies and public education programs will also help to make Utah a safer place to live, travel, do business and recreate (2).

**4) Increase capacity**
Given the state's current increases in both travel and population, it is inevitable that capacity will have to be added to the existing system. However, financial constraints may prevent the department from building highways fast enough to completely eliminate congestion. With $16.5 billion in unmet highway needs through the year 2030, the department will continue to explore alternative financing methods as a means of constructing projects in a much shorter time line. (2)

With these priorities in mind, the paper will now discuss the UDOT pavement management system and its integration into the AMS.

## PAVEMENT MANAGEMENT AT UDOT

Pavement Management at UDOT is an ongoing effort throughout most of the department and organizationally is located within the Systems Planning and Programming section under the Director of Asset Management (3). UDOT has been utilizing a computerized pavement management system (dTIMS CT

developed by Deighton) for the management of the UDOT pavement network since the early 1990's. The initial implementation of the pavement management system was completed in 1993 and the data, models and analysis have been enhanced since that time. UDOT employs a steering committee made up of the pavement management central office staff and the regional pavement management engineering and design staff to oversee the configuration of the PMS. The PMS that is implemented within UDOT allows UDOT to configure any aspect of the database and any of the analysis and economic parameters without the need for any software modification. As new innovations are developed in the science of pavement management and asset management, such as the calculation and implementation of Remaining Service Life (RSL) analysis, UDOT can take advantage of those innovations without the need for costly software upgrades.

Network level analysis is done in the Central Pavement Management group using pavement condition data, which is collected each year using a combination of visual distress rating procedures and automated collection systems for IRI, rut depth and faulting. The PMS database facilitates the integration of this pavement condition data with the state's inventory, traffic, maintenance and construction history data. As well, the PMS database facilitates the calculation and transformation of this data into the pavement sections used during the Lifecycle Cost (LCC) analysis through a process called Concurrent Transformation. Once the data has been transformed to the pavement analysis sections, the indexes calculated based on the measured conditions are used to generate and select the optimum treatment strategy that is required for each pavement section based on various budget scenarios.

This flexible analysis process allows the PMS to provide an optimized maintenance and rehabilitation plan based on a given set of budgets and any desired distribution of those budgets into user defined budget categories. This same analysis flexibility allows the PMS to develop and report funding needs and funding requirements by allowing UDOT to determine the required amount of funding to achieve different objectives using an unlimited number of scenarios. For example, UDOT can determine the funding levels required to eliminate backlog over a certain number of years, the funding levels to maintain the network in a status quo condition, to increase an overall pavement condition by 5% or any other objective based on the network wide analysis.

The process can be used to identify the funding requirements for future years to maintain the system condition at the desired levels. With an approved funding level the model can then select the pavement sections and recommend the appropriate maintenance and rehabilitation treatments. The recommendations from the pavement management system from the Central Pavement Management group are then reviewed with the Regions and the Asset Management Group to develop the list of Statewide Transportation Improvement Program. (STIP)

**The PMS Analysis**

During the pavement management analysis, the PMS produces a set of alternative treatment strategies consisting of one or more treatments applied during the pavement's life cycle for each section of pavement along the UDOT highway network. In order to develop these alternative strategies, the PMS completes the following:

- Generates and manages performance measures from pavement input data for each section of highway to be analyzed;
- Forecasts performance measures into the future using performance models specific to various pavement families;
- Investigates every viable treatment in each year of the analysis based on triggering rules and decision trees that UDOT has defined.
- For each treatment that is applicable, the PMS applies the treatment, resets the performance measures affected by the treatment and then evaluates the future performance measures as well as the costs of the treatment.
- Once the initial treatment is applied, the PMS checks to see if a subsequent treatment can be applied in conjunction with the primary treatment before the end of the analysis. If so the subsequent treatment is applied, the performance measures reset (as applicable) and the future values for each performance measure are evaluated once again.
- This process is repeated multiple times for each pavement section so that a comprehensive list of strategies can be generated. An example set of strategies for a pavement section might look as follows:

- Functional Overlay in 2010 and Open Graded Seal in 2017 and Open Graded Seal 2026
- Functional Overlay in 2010 and Open Graded Seal in 2018
- Functional Overlay in 2010 and Functional Overlay in 2020

- Once the strategies are generated, the PMS calculates the costs and benefits of the strategies so that the most cost effective strategy can be selected depending on the budget available.

A sample treatment strategy is displayed in Figure 1. This strategy has one treatment in 2009 and a subsequent treatment in 2016. Strategies generated by the pavement management system can have as many as four treatments in a typical analysis period depending on the parameters used to configure the analysis and the length of the analysis period.

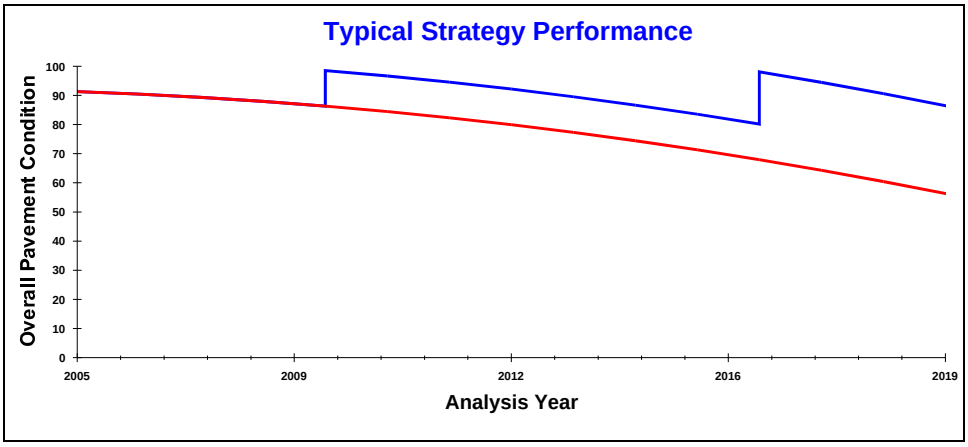



**Figure 1: Example Treatment Strategy**

In general, depending on the configuration parameters, a typical analysis will produce between 50 and 150 different alternative treatment strategies for a pavement management section. The UDOT analysis generates approximately 188,000 alternative treatment strategies over the analysis period.

When the treatment strategies are graphed according to their costs and benefits, the graph will look like the following graph displayed in Figure 2.

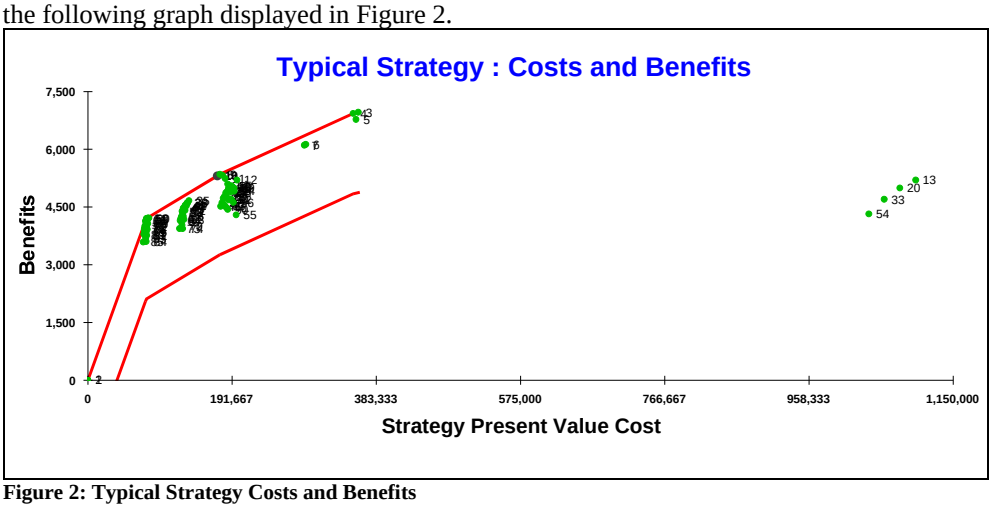



**Figure 2: Typical Strategy Costs and Benefits**

In Figure 2, each treatment strategy is plotted as a single dot according to the calculated net present value cost and benefits for the treatment strategy. The area in which the analysis will consider treatment strategies is called the efficiency zone and is defined by the two red lines. The PMS optimization decides which strategy is the best strategy for the segment depending on the funding dollars that are available and how those dollars are allocated between preservation and rehabilitation treatments and the objective function that the analysis supports.

On a network wide basis, the optimization starts with the highest benefit cost ratio and then moves within the efficiency zone to see if better strategies can be selected. This search continues until all of the available funding is used up and no more strategies can be selected for the funding that is available.

Once the optimization is completed, UDOT can then investigate the analysis results using numerous reports, charts and graphs that effectively communicate the changes in condition that result from the various investment scenarios included within the analysis. When the investigation is complete, UDOT can output the recommended strategies for each pavement section and provide those recommendations to planning for inclusion within the long-range plan and to the regions for inclusion in the STIP.

## ASSET MANAGEMENT AT UDOT

The Director of Asset Management and the Asset Management Engineer within Systems Planning and Programming section at UDOT are responsible for the implementation of asset management within UDOT and for the implementation and operation of the AMS. Since 2002, the AMT has been expanding the use of the AMS to include additional assets and to refine and enhance the analysis.

The implementation of the AMS at UDOT was first envisioned as only the implementation asset management database and analysis tools, which would enable UDOT to perform "cross asset analysis and optimization". This mistaken belief that UDOT would be practicing good asset management by implementing an asset management system comprised only of a decision support database and several analysis tools led Deighton to refer to this as the ***Asset Management Paradox*** which will be discussed in the following section.

### The Asset Management Paradox

The Asset Management Paradox simply defined is the realization that an asset management system can not be implemented in any agency unless that agency first adopts best practice asset management. Therefore, implementing an asset management system is not necessarily in itself good asset management although good asset management requires the implementation of an asset management system.

To put it another way, implementing an asset management system which is capable of performing cross asset analysis and optimization will only deliver the full benefits and promise of asset management in an agency that has undertaken and adopted components of best practice asset management that help determine exactly what level of service they are providing to their customers (the traveling public). Implementing an AMS as a decision support tool requires first that the agency becomes aware that a decision support tool is needed and where precisely that decision support tool fits in their organization structure. The AMS implementation must be outlined within the agency's asset management strategy and implementation plan. It is crucial that an agency first develop the asset management strategy and an asset management implementation plan to address the asset management needs of the agency prior to seeking a set of decision support tools to become the basis of an AMS. The asset management strategy and the implementation plan when completed will pinpoint the exact requirements of an asset management system and where that system should fit within the agency.

Conquering the asset management paradox and changing the paradigm within UDOT would be the first and the most challenging aspect that Deighton would face throughout the initial stages of the AMS implementation project within UDOT.

Asset management for transportation agencies is not a set of computer tools that enable the economic analysis of assets within and across all asset groups, but rather, a broad based business approach to managing assets that clearly links the actions of the transportation agency to specific measurable goals and objectives documented and published in the agency's transportation service strategic plan. Any decision support software tools that form the basis of an AMS are considered only one piece of the broader asset management puzzle that assists decision makers to make better decisions with respect to their strategic transportation goals and objectives.

The difference between asset management and an AMS can best be thought of as follows: "***An agency practices asset management so it can deliver a transportation service to its community. At the same time, an agency uses an asset management system so it can use a systematic practical approach to practicing asset management."(4)***

This shifting of UDOT away from strictly a "decision support system based" solution for asset management to a more "broad based business approach" to asset management was necessary to ensure successful adoption of asset management best practice and a successful implementation of an asset management system at UDOT. Other agencies should benefit from this knowledge and from UDOT's experience and realize

that there is a separation between implementing asset management and implementing an asset management system.

**Asset Management at the Strategic Level**

Asset management at the strategic level is used to make funding allocation decisions across asset groups (pavement, bridge, safety, maintenance and mobility) and to provide UDOT executives with information based on integrated asset data and analysis across the DOT. Early on in the implementation of the AMS, UDOT executives expressed the need to be able to report system condition and the effects on a wide variety of performance measures based on many different investment strategies.

The implemented AMS allows for a "stove-pipe" type analysis for any of the assets loaded into the system and allows for an economic trade off analysis using the AMS "cross-asset analysis and optimization" functionality. At present, individual asset condition performance measures and RSL are used within the AMS to determine funding levels, trade-offs and to develop reports for TRANSAT and the Transportation Commission. UDOT continues to investigate additional performance measures such as risk, asset value, written down replacement cost, delay costs, user costs, environmental impacts, societal impacts and economic impacts but those have not been factored into the cross asset analysis and optimization at the present time. In the future UDOT will increasingly rely on this technology once the additional cross asset analysis and optimization performance measures have been developed and approved by the TRANSMAT steering committee. At present, the AMS has completed trial runs of the "cross asset analysis and optimization" using condition performance measures only but the widespread use and implementation of the "cross asset analysis and optimization" functionality is still under investigation by UDOT and further modification and enhancement by Deighton.

The AMS imports data from the respective tactical asset level systems and produces funding impact reports, charts and graphs as well as initial program recommendations based on selected investment scenarios. The results of the analysis are examined by TRANSMAT and a funding investment strategy is approved by TRANSMAT. The approved funding investment strategy includes amounts for preservation and rehabilitation for each asset and includes investment dollar amounts for various planning horizons (5 Year STIP Development, 10 Year System Preservation Plan and the UDOT Long Range Plan (LRP)).

**Asset Management at the Tactical Level**

Asset management at the tactical level within UDOT involves separate management systems designed and implemented for each specific asset. Funding allocation decisions and project recommendations from the strategic level are passed down to the tactical level management systems to form the basis for more asset-specific analyses. Within each asset group, the performance measures of each asset are used to determine the effective mix of preservation and rehabilitation funding. These performance measures at the tactical level may be different than those at the strategic level as the asset management system matures over time. The asset groups use their respective management systems to determine recommended projects for each individual asset.

With the PMS, at the tactical level, incremental benefit/cost optimization is used to determine recommended projects and to compare preservation strategies, repair strategies, rehabilitation strategies and replacement/ reconstruction against one another to come up with the optimum strategy of one or more treatments for an asset within the analysis time frame. Life-cycle costs are used to determine effective funding needs for each asset group.

When the tactical level asset groups have completed their analysis, the recommendations are harmonized with other asset group recommendations and then used in the development of the STIP, the 10 Year System Preservation Plan and the LRP.

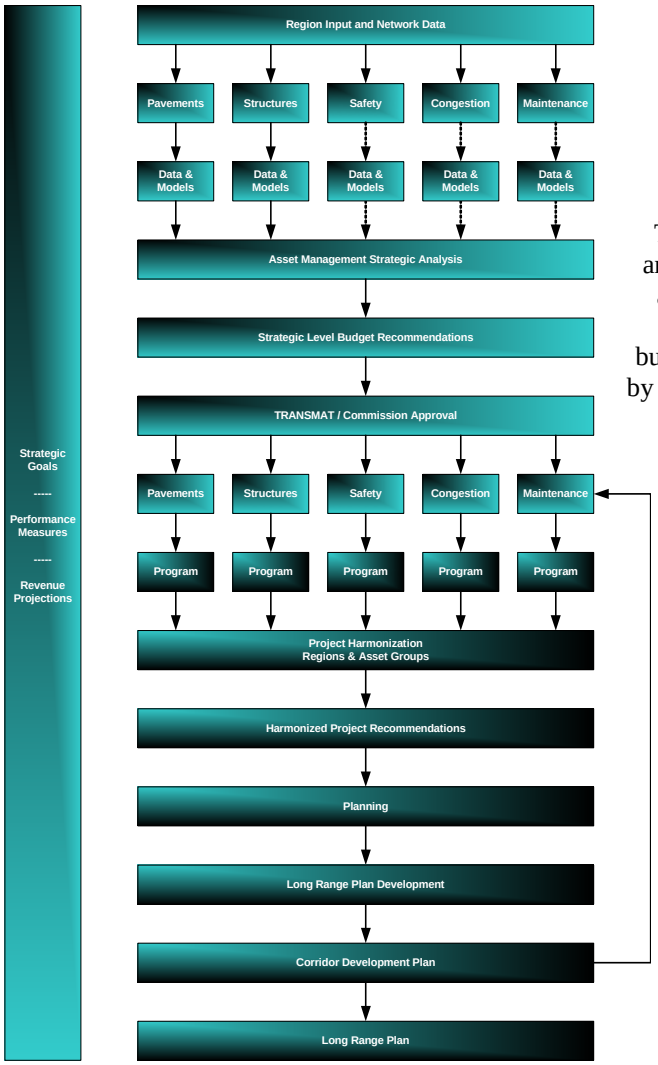
**Asset Management at the Operational Level**

In order to implement asset management at the operational level within UDOT, UDOT has implemented a region specific tool call the "Plan for Every Section". This tool consists of a database that contains the semi-annual inspection information for each maintenance section, and the routine maintenance schedule based on condition and treatment life data. UDOT is also in the process of implementing a web based maintenance management system. This new system will help supplement the operational, tactical and strategic asset management initiatives within UDOT.

**THE UDOT PLANNING MODEL**

In order to illustrate the integration and coordination of asset management planning and program development, the UDOT Planning Model was developed. It serves as a model of data and program flow within UDOT and clearly outlines the planning process.

Figure 3 illustrates the UDOT Planning model with descriptions to the right of the diagram. .




Asset Group Systems are used to store asset specific data and models. As an example, UDOT uses PONTIS to enter bridge condition and inventory data. This data is exported to the AMS on a semi-annual basis for analysis.

The AMS at the strategic level is fully configurable and customizable to load data collected in any of the asset group systems. Once the data and models are configured, the strategic analysis is completed and budget recommendations are presented and approved by TRANSMAT and the Transportation Commission.

The approved budget recommendations and initial project recommendations from the AMS are delivered to the asset groups for program development. The recommendations coming from the tactical asset groups are then harmonized into a complete set of recommendations for each asset group. Harmonization uses a mix of automatic and manual processes to adjust projects within the same highway segment across program areas. This enables UDOT to take a more "corridor type" approach to programming to ensure that programs across asset groups maximize efficiency and minimize costs.

The harmonized project recommendations are then delivered to planning for inclusion in the LRP.

**Figure 3: UDOT Asset Management Strategic Planning Model (1)**

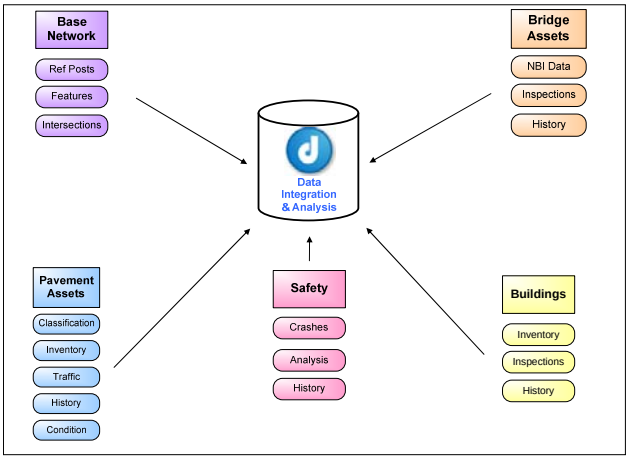
At the completion of the Long Range Planning stage, UDOT will have a list of corridors that will be reconstructed or reconfigured and any assets on those corridors may then have what would be considered a finite life. The preservation and rehabilitation dollars that were allocated to those assets from the tactical asset group program recommendations can then be used to help fund the reconstruction or can be freed up for other preservation and rehabilitation needs.

## MANAGEMENT SYSTEM INTEGRATION

Integrating the individual management systems within the AMS has been accomplished through the inherent flexibility of the AMS in terms of its user definable database structure and its completely flexible analysis process. The AMS is expandable and new hard assets (section or point assets) or soft assets (like safety) can be added to the system at anytime without any programming or software enhancements required by the AMS developers.

**The AMS Database**

The AMS Database is organized into a series of user definable tables, which are called Perspectives. A Perspective can be thought of as a different view of the transportation network. For example, when one examines functional classification data, one would see the data representing a length of road within the transportation network. A perspective that stores the functional class data would be a section perspective containing many records to indicate where the functional class data changes throughout the network. Bridge data, on the other hand, exists as discrete points along the network and is stored within the AMS separately from any other asset data. A description of the concepts of perspectives, which are used to integrate the data from the tactical level systems, is displayed in Figure 4.




Each client determines which data to integrate within the AMS and configures the AMS to store and maintain that data through menus and parameters and not through programming.

The UDOT AMS contains perspectives to store the highway network definition data, location reference data, pavement data, bridge data, accident data, traffic data, mobility data, and maintenance data.

UDOT can modify and enhance the structure of the AMS database at anytime to add additional data describing the existing assets in the system or UDOT can add entirely new assets to the AMS.

**Figure 4: AMS Data Integration**

Asset location information (where assets are located in the network) and asset attribute information are exported from the tactical asset management systems and imported in the AMS. UDOT is currently investigating the development of an agency wide corporate database, which the AMS will link to in the future for retrieving the data necessary for analysis. Each of the tactical asset group systems export their data to external files on a periodic basis and updates are made to the data within the AMS through importing.

When the UDOT PMS was first implemented, UDOT established and published the Location Reference System and put in place policies and procedures that continue to this day to ensure the current definition of the highway network and its Location Reference System is readily available throughout UDOT. The PMS and the AMS contain the current definition of the Location Reference System at all times to facilitate the integration of asset data. Unfortunately other legacy systems within UDOT do not have the technology to maintain asset location data according to the latest version of the LRS and that data can be somewhat difficult to integrate into the AMS as some databases contain LRS information from the mid 1990s. In order to help alleviate this situation, UDOT is implementing a Location Reference System Engine that will help translate between different versions of the LRS and help to make integrating asset data not collected on the current version of the LRS easier and less time consuming.

**The AMS Analysis**

The UDOT Planning model described previously in the paper describes the AMS analysis from an organizational standpoint, but not from a technical standpoint.

When working at the tactical asset management level, the analysis follows the framework outlined in Figure 5. Typically one set of strategies is generated for each pavement section, then many budget scenarios are optimized to determine impacts of different investment scenarios and investment strategies, on the performance of the asset through the planning horizon.

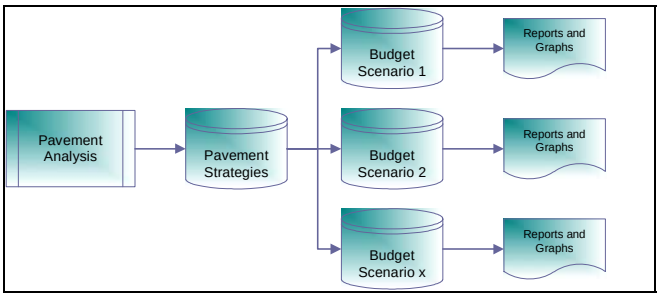



**Figure 5: Single Asset Analysis Framework**

In a Strategic Level Asset Management System, the analysis framework as displayed in Figure 6 differs significantly as many different types of analysis can be completed. The strategies generated for pavements and for bridges may include each individual pavement section or bridge and hundreds of preservation and rehabilitation strategies could be generated for each asset. Analyses for other assets such as signs may not include each and every sign, but might involve analyzing total signs in each region or district instead which would produce investment strategies on a regional basis for signs and not an investment strategy for each individual sign. Other hard and soft assets that fall under the category of maintenance such as pavement markings, line striping, litter pickup, vegetation and weed control may be examined state-wide and investment strategies would report overall condition throughout the sate and not on an individual or even regional basis.

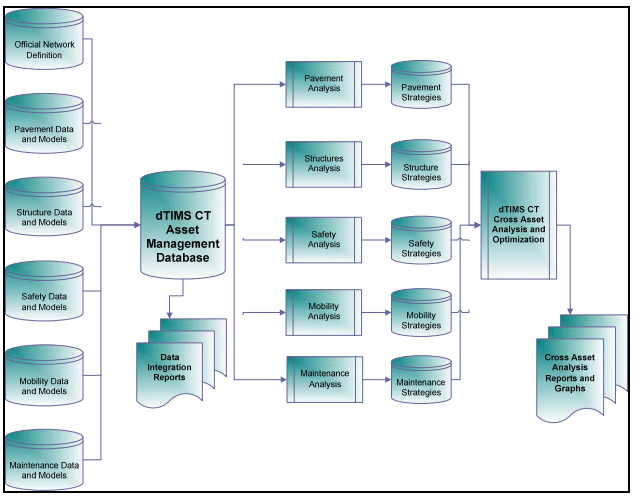



**Figure 6: "Cross Asset Analysis and Optimization" Analysis Framework**

When the strategies have been generated, the AMS allows for the optimization of those strategies to produce investment scenarios for each asset individually or across asset groups. The AMS then can produce reports and graphs to illustrate the differences in asset condition and any other performance measures (impacts on the economy, society, and the environment) for each investment strategy and each asset. UDOT can determine the immediate effects of transferring investment dollars from preservation to rehabilitation, one asset to another and any combination.

## CONCLUSIONS AND RECOMMENDATIONS

UDOT continues to implement and enhance the AMS and integrate its analysis capabilities into the strategic, tactical and operational asset management areas of UDOT. Like any new technology, UDOT continues to determine what the system is capable of and what capabilities UDOT is going to utilize.

Flexibility is the key to implementing asset management within an organization and for implementing an asset management system. There is no one "silver bullet" asset management solution that will work for every agency, each agency must determine which best practice components of asset management to implement and the timelines for that implementation. Asset management is about people, policies and procedures as well

as products and UDOT has been successful at implementing widespread organizational and policy changes because it has concentrated not only on the AMS itself but the implementation of asset management as a whole throughout UDOT.

In order for asset management to be successful in an agency, that agency must be committed to asset management best practice and must put in place strategies and implementation plans to ensure the adoption of asset management best practice across the agency.

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