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COST/BENEFIT ANALYSIS OF ENTERPRISE-WIDE GEOGRAPHIC INFORMATION SYSTEM IMPLEMENTATION: CASE OF THE ILLINOIS DEPARTMENT OF TRANSPORTATION

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Abstract

This research is an in-depth investigation of the costs and benefits of Geographic Information System implementation in the Illinois Department of Transportation. It presents a methodology to determine the cost effectiveness of the implementation of this enterprise e-government information technology.

The Department conducted an organization-wide effort to portray GIS capabilities and to identify and select specific GIS project candidates based on management priority, ease of implementation, and user commitment. A comprehensive Cost/Benefit analysis was then developed over Fiscal Years 1995 to 2004. The greatest portions of costs, over the ten-year timeframe, were for personnel (67%) and consultant services (19%). The research developed two estimates of benefits: Efficiency Benefits and Effectiveness Benefits. The results of this Cost/Benefit analysis of GIS implementation yielded a Net Present Value of $2.9 million and an Internal Rate of Return of 99.8% over the Fiscal Year 1995 to 2004 analysis period.

Keywords: Geographic Information Systems (GIS), cost/benefit analysis, feasibility, management information systems (MIS)

Background

The Illinois Department of Transportation (IDOT) is a large state transportation agency with a $3.9 billion operating budget, a 17,000-mile roadway system and the third largest metropolitan area in the United States, Chicago, and a key position geographically in interstate commerce. GIS technologies had the potential to effect multiple productivity improvements across the enterprise. These resulted from GIS's unprecedented capability to integrate information into readily understandable formats focused on individual user decision support needs including those of executives.

However, GIS presented a complex information technology implementation problem due to these enterprise-wide characteristics. Individual GIS projects were unique at each individual user level in terms of applications, complexity, the sources and diversity of information, and the accessibility and use of hardware and software. An operational GIS would ultimately change IDOT information flows, work assignments and decision-making processes.

IDOT initiated GIS investigation efforts in 1995 (Hall, 1999). By June 1997, the Department had reached an important decision point in its GIS implementation efforts. The Department had accomplished the evaluation of GIS technologies, the selection of a GIS platform, the conceptual outline of GIS data structures, the creation of an extensive GIS demonstration package, and the approval by executive management to continue implementation activities.

The next step was the development of a comprehensive Cost/Benefit Analysis of GIS implementation to fully evaluate economic and organizational feasibility. Ultimately, executive management would decide on the appropriate implementation strategy. The Cost/Benefit Analysis would be an important component for this determination. Due to space limitations, the following is a summary of the comprehensive Cost/Benefit Analysis. A more detailed depiction of the analysis is available in References 2 and 3 (Hall, 1999) (Hall et al., 2000).
GIS Project Identification And Scope Determination

The Cost/Benefit Analysis required the determination of the future scope and timing of GIS applications. The Department's strategy for advancing organizational learning of GIS capabilities encompassed two actions: presentations of a GIS demonstration packages and the completion of a GIS project evaluation forms.

During 1997 and early 1998, the Department presented the opportunity to all organizational areas and levels to attend demonstrations of GIS capabilities. These included an individual presentation at all nine district offices. Subsequently, the participants were asked to identify the specifics of potential GIS activities through means of a project evaluation form which helped identify the scope of candidate projects, estimated costs, and tangible/intangible benefits.

The criteria the Department used the to define, rank and select projects included user area interviews, upper management priorities, external analyses, ease of implementation rankings and user commitment ratings. Fourteen projects were then selected as those with medium to high Department priority that could reasonably be put into production within the five-year timeframe. Table 1 lists these projects.

The selected GIS projects provided the basis for the scope of implementation over Fiscal Years 2000 to 2004. Although these projects were not exhaustive, they provided a sound basis for accomplishing the Cost/Benefit Analysis.

Costs Determination

The following categories were selected for the determination of IDOT GIS implementation costs over Fiscal Years 1995 through 2004: personnel, hardware and equipment, software, consultant services and miscellaneous (Hall, 1999). These costs were directly related to GIS activities. Indirect costs were considered if they encompassed a substantial expenditure directly related to the GIS project.

There were two categories of costs. Historical costs were costs previously incurred from Fiscal Years 1995 through 1999. Documentation of the previous GIS investigative and deployment effort provided the identification of these costs. Future costs were the anticipated costs from the GIS project scope of implementation over the five-year period encompassing Fiscal Years 2000 to 2004. Table 2 summarizes the estimated costs for GIS implementation.

For staffing, Fiscal Years 1995 to 1999 provided reasonable estimates of the time dedicated to GIS development and implementation activities. Future staffing costs included continued staffing for the GIS Development Group for central GIS development/support activities and end user GIS staffing requirements based on the major GIS projects. Costs for data acquisition were included in personnel costs although these were minimal since most applications used existing databases.

Initial hardware costs encompassed the acquisition of hardware necessary to run GIS development software including PC workstations and printer/plotters. The estimated future costs for Fiscal Years 2000 to 2004 were based on the scope of user area deployment and equipment upgrades for the GIS Development Group.

For software, the high initial costs were for the acquisition of GIS development software in Fiscal Years 1995 and 1996. Subsequent costs included user area software, anticipated software upgrades and the purchase of new software tools for GIS data analysis and Internet applications. Consultant expenditures were necessary for assisting the development of the larger, more complex GIS projects. Miscellaneous costs included those for training, annual software maintenance and travel.

Table 2 displays the costs for each of the five cost categories by Fiscal Year. Many of the identified costs, especially staffing, would have occurred without GIS implementation. However, GIS implementation activities came at the expense of other Department activities and thus represented a true cost to IDOT.

From Table 2, the largest cost category was for staffing the GIS effort (67%). This coupled with the amount for outside consultant expertise accounted for 86% of the total cost over the ten-year period. Hardware and software costs represented a total of 8% and 2% respectively. These costs confirm the importance of staffing in MIS implementation efforts. For IDOT, headcount had steadily decreased 15% from 1990 to 1998 (Hall, 1999). GIS implementation would require a redirection of existing personnel from other activities.
**Table 1. Major GIS projects for the Illinois Department of Transportation**

<table>
<thead>
<tr>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway Inventory Management</td>
</tr>
<tr>
<td>Internet Road Conditions</td>
</tr>
<tr>
<td>Traffic Count Work Map</td>
</tr>
<tr>
<td>Pavement Asset Management</td>
</tr>
<tr>
<td>Mapping</td>
</tr>
<tr>
<td>Multi-Year and Annual Program Development</td>
</tr>
<tr>
<td>Bridge Asset Management</td>
</tr>
<tr>
<td>Accident Mapping and Analysis</td>
</tr>
<tr>
<td>Census Update</td>
</tr>
<tr>
<td>Material Supplier Location Mapping</td>
</tr>
<tr>
<td>Aerial Photography Index</td>
</tr>
<tr>
<td>Permits</td>
</tr>
<tr>
<td>Environmental Analysis</td>
</tr>
</tbody>
</table>

**Table 2. Total Estimated Costs for GIS Deployment in the Illinois Department of Transportation (Thousands of Dollars)**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Staffing</td>
<td>31</td>
<td>159</td>
<td>371</td>
<td>482</td>
<td>770</td>
<td>846</td>
<td>1,187</td>
<td>1,201</td>
<td>1,300</td>
<td>1,690</td>
<td>$8,037</td>
</tr>
<tr>
<td>Hardware</td>
<td>196</td>
<td>6</td>
<td>39</td>
<td>12</td>
<td>180</td>
<td>38</td>
<td>227</td>
<td>88</td>
<td>68</td>
<td>103</td>
<td>$957</td>
</tr>
<tr>
<td>Software</td>
<td>38</td>
<td>40</td>
<td>24</td>
<td>9</td>
<td>26</td>
<td>11</td>
<td>19</td>
<td>27</td>
<td>21</td>
<td>28</td>
<td>$243</td>
</tr>
<tr>
<td>Consultants</td>
<td>0</td>
<td>144</td>
<td>218</td>
<td>121</td>
<td>128</td>
<td>360</td>
<td>360</td>
<td>300</td>
<td>250</td>
<td>300</td>
<td>$2,241</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0</td>
<td>9</td>
<td>33</td>
<td>41</td>
<td>45</td>
<td>57</td>
<td>69</td>
<td>61</td>
<td>58</td>
<td>60</td>
<td>$433</td>
</tr>
<tr>
<td>Total</td>
<td>265</td>
<td>358</td>
<td>685</td>
<td>665</td>
<td>1,149</td>
<td>1,312</td>
<td>1,862</td>
<td>1,737</td>
<td>1,747</td>
<td>2,131</td>
<td>$11,911</td>
</tr>
</tbody>
</table>

**Benefits Determination**

Benefits from information technologies are traditionally difficult to determine especially when evaluating the implementation of a new information technology such as GIS (Huxhold et al., 1995). It can be extremely difficult to predict GIS’s comprehensive impact on operations as implementation and assimilation occurs. The technology may result in the complete redesign of some organizational processes. Other existing tasks may simply improve in efficiency. GIS implementation will almost certainly result in better decisions although these may not be readily determined or quantified beforehand. Despite these uncertainties, there was still a need to quantify benefits to perform the Cost/Benefit Analysis.

**USGS Method for Categorizing Benefits**

Gillespie has developed a model to determine benefits for the United States Geological Survey (USGS). He described a method for categorizing GIS benefits as efficiency benefits and effectiveness benefits (Gillespie, 1994).

Gillespie defined **Efficiency Benefits** as those that “result when a GIS is used to do a task previously done without a GIS; the same quality of output is produced but at lower cost.” For example, the automated display of pavement condition information rather than manual map preparation. He also defined **Effectiveness Benefits** as those that “result when a GIS is used to improve the quality of a current output, or to produce an output not previously available; the GIS is used to do something that could not or would not be done without it.” For example, when GIS enables the previously unavailable comprehensive visual analysis of new roadway project alignments.

In general, **Efficiency Benefits** are easier to estimate based on automation of existing operations. But measurement of **Effectiveness Benefits** will provide “a better understanding of where and how GIS technology is useful, so that organizations can invest their GIS dollars wisely and well.” Given the enterprise-wide nature of GIS impact on IDOT operations, this paper will categorize benefits for both Efficiency and Effectiveness Benefits.
Efficiency Benefits

Efficiency Benefits were based primarily on the end user area evaluation of estimated personnel savings by position level of a fully implemented GIS project. The majority of the estimated Efficiency Benefits resulted from the GIS-enabled replacement of existing map preparation functions. Significant personnel efficiencies resulted in the mapping, inventory, program development, traffic counting and census mapping areas. Additional benefits for savings in travel, supplies and other miscellaneous costs represented less than 1 percent of the total benefits. Table 3 portrays the total estimated value of Efficiency Benefits (Hall, 1999).

Table 3. Total Estimated IDOT Efficiency and Effectiveness Benefits by Category for GIS Deployment Activities by Fiscal Year (Thousands of Dollars)

<table>
<thead>
<tr>
<th>Category</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency Benefits</td>
<td>$270</td>
<td>$921</td>
<td>$1,908</td>
<td>$2,026</td>
<td>$2,280</td>
<td>$2,961</td>
</tr>
<tr>
<td>Effectiveness Benefits</td>
<td>$0</td>
<td>$1,000</td>
<td>$4,414</td>
<td>$7,828</td>
<td>$7,828</td>
<td>$7,828</td>
</tr>
<tr>
<td>Grand Total</td>
<td>$270</td>
<td>$1,921</td>
<td>$6,322</td>
<td>$9,854</td>
<td>$10,108</td>
<td>$10,789</td>
</tr>
</tbody>
</table>

Effectiveness Benefits

There were many potential Effectiveness Benefits in IDOT resulting from the GIS including the ability to quickly visualize interrelationships of data and projects, quick response to management queries and to assist in communications with the legislature, regulatory agencies and the general public.

Most of these intangible benefits were readily apparent but also difficult to quantify. For the purpose of this Cost/Benefit analysis, two high priority IDOT organizational activities were selected for Effectiveness Benefits evaluation: accident analysis and program development. These areas were selected based on their potential magnitude of benefits to IDOT, executive management interest and their capability for reasonable quantification.

GIS would enable major improvements in operational effectiveness through improved decision support tools. These Effectiveness Benefits were determined through interviews with upper level decision-makers in the affected organizational areas. These managers were knowledgeable in existing IDOT decision-making processes and the new decision support products that an IDOT GIS would provide.

Accident Analysis and Remediation

The economic impact of motor vehicle crashes is substantial. The National Safety Council has developed economic costs for evaluating motor vehicle accidents. These costs ranged from $6,100 for a property damage accident to $34,200 for a nonfatal disability injury to $810,000 for a fatality (National Safety Council, 1996). There were 462,049 motor vehicle crashes in Illinois in 1995 including 99,320 personal injury and 1,402 fatal crashes. The total economic burden in Illinois for these crashes totaled $5.8 billion (IDOT, 1995). Any reduction in motor vehicle crashes represented a potentially substantial benefit.

The Department annually identified High Accident Locations (HAL) on the state highway network. HALs indicate areas where there are overrepresentations of accidents based on accident density/type/location and roadway characteristics. HAL determination criteria also include roadway inventory information such as average daily traffic and number of lanes (Hall, 1999).

High accident location information is one of the primary selection criteria used in the safety program development process. Annually, of the 2,000 plus identified HALs, the Department programmed approximately 100 to 150 sites for remediation and improvement (IDOT 1994).

Prior to GIS, the accident data had been deficient in quality to satisfy the needs of the program development staff with an up to two year delay in HAL site identification, limited availability of individual accident information and nine year old roadway inventory information (Hall, 1999). Previous Department studies confirmed the importance of knowledge of accident types/frequencies and roadway characteristics in selecting the appropriate wet accident countermeasure in reducing the frequency of future accidents (IDOT, 1995).

GIS had the potential to significantly improve the efficiency of safety program development activities by providing access to more current HAL, accident and roadway information. GIS would facilitate analysis of accident locations through the integration of...
previously disparate data elements. For example, the incorporation of accident types and conditions with roadway inventory characteristics such as lane width, surface type, friction number and shoulder type would enable more effective multi-variable analysis. Geographic displays would enable visual and cluster analysis and provide a means of data integration for future data mining and cluster analysis activities.

Based on interviews with district and central office personnel directly involved in the selection of projects to address HALs, Effectiveness Benefits would result from the selection of more appropriate safety projects and remediation measures. They also estimated GIS would assist in better prioritizing project selection and remediation measures for two thirds of high accident projects or approximately 65 to 100 projects annually. A conservative 15% increase in effectiveness in accident reduction provided an estimated Effectiveness Benefit for accident analysis and remediation at High Accident Locations at $1,000,090 annually (Hall, 1999).

Annual and Multi-Year Program Development

The roadway program development process is a critical function in the Department. Every year the Department develops and publishes the Annual and Multi-Year programs based on roadway and structure needs, fund availability, district priorities and public input. The fiscal year 2001 Annual Roadway Program for IDOT is $2.3 billion.

Program development functions use information from program, project and inventory databases. The 1999 program development process had some major weaknesses including difficulties in producing project maps, inability to access road and structure inventory files and unattainable historical information.

Since the amount of money available to improve the roadway network is relatively fixed, the value of better decisions would lie in the ability to better prioritize projects through accessing more comprehensive information. GIS would provide, for the first time, a means to readily integrate information from programming, inventory and accident databases and in visual displays to enable better decisions in project selection.

Department management estimated that a fully redesigned programming database and implementation of GIS would result in the replacement of 10% of the projects in the annual program. Specifically, Effectiveness Benefits in program development would result from user benefits and improved pavement life.

User benefits result from a reduction in traveling on rough pavement. Mosheni, Darter and Hall investigated the benefits to the highway agency and the traveling public of improved pavement management practices (Mosheni et al., 1992). A more structured consideration of the higher traveled sections and rehabilitation options in project rehabilitation selection and timing would result in less traffic on roads with a with a fair to poor condition rating. The Effectiveness Benefits resulting from increased user benefits of improved program development from GIS capabilities were estimated as $2,028,000 annually.

For improved pavement life, the application of GIS would provide a better method to incorporate additional information on which to choose more effective rehabilitation strategies resulting in a longer expected life to the network. Program development staff conservatively estimated that a more effectively applied rehabilitation strategy would extend the project life of one out of every ten projects by one year resulting in an annual Effectiveness Benefit of $4,800,000 (Hall, 1999).

These estimated annual GIS Effectiveness Benefits for program development are relatively large numbers. However, the perceptions of program development practitioners and executive management recognized the decision support value of GIS in future programming decisions.

Summary of Efficiency and Effectiveness Benefits

Table 3 summarizes the total estimated Efficiency and Effectiveness Benefits resulting from GIS implementation. The Effectiveness Benefits were not all inclusive. Many other operational and decision-making areas could potentially warrant analysis to attempt to quantify intangible benefits. However, the incorporation of accident analysis and program development Effectiveness Benefits provided a rational representation for the Cost/Benefit Analysis.

Cost/Benefit Analysis

Table 4 outlines the total estimated costs and benefits for GIS implementation over the fiscal year 1995 to 2004 timeframe (Hall et al, 2000). Efficiency Benefits start to overtake total costs in fiscal year 2001.
Using a discount rate of 3% in analyzing Net Present Value yields a positive value of $24.1 million for IDOT’s GIS implementation based on the estimated costs and benefits (Metcalf, 1978). The Internal Rate of Return equated to 99.8%. The projected IRR exceeds IDOT’s cost of capital of 3% justifying IDOT’s efforts towards GIS implementation. IDOT can also use the IRR to evaluate GIS efforts against other projects that may be in competition for organizational resources.

Conclusions

The Cost/Benefit Analysis of GIS implementation in the Illinois DOT provided information on the organizational costs and benefits to determine economic/organizational feasibility and direct resource allocation. The development of a detailed scope of implementation provided reasonable estimates of costs and Efficiency Benefits.

The determination of Effectiveness Benefits for accident analysis and program development effectively portrayed the broad scope of decision support benefits of GIS implementation and the justification for future development. There were many competing efforts for Department resources, including equipment, personnel and contractual services. The Cost/Benefit analysis provided IDOT with knowledge to make these strategic decisions.

<table>
<thead>
<tr>
<th>Table 4. Summary of Total Estimated Costs and Benefits for GIS Deployment in the Illinois Department of Transportation by Fiscal Year (Thousands of Dollars) (Hall et al., 2000)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Historical</strong></td>
</tr>
<tr>
<td>Total Costs</td>
</tr>
<tr>
<td>Total Benefits</td>
</tr>
<tr>
<td>Benefits Minus Costs</td>
</tr>
</tbody>
</table>

References


