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**Cost Estimates for Near-term Deployment
of Advanced Traffic Management Systems**

Final Report

by

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Prepared for the

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FINAL REPORT
Cost Estimates for Near-term Deployment
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Objective

The objective of this study is to provide cost estimates for the next five years for engineering, design, installation, operation and maintenance of Advanced Traffic Management Systems (ATMS) in the largest 75 metropolitan areas in the United States. The areas are listed in order of total population in Table 1.

Scope of Report

This report gives estimates for deployment costs for ATMS in the next five years, subject to the qualifications and caveats set out in following paragraphs. The report considers infrastructure components required to realize fully a functional ATMS over each of two highway networks (as discussed in the Section describing our general assumptions) under each of the four architectures identified in the MITRE Intelligent Vehicle Highway Systems (IVHS) Architecture studies [Ref 1]. The architectures are summarized in this report in Table 2. Estimates are given for eight combinations of highway networks and architectures.

Summary of Results

We estimate that it will cost between \$8.5 Billion (minimal network) and \$26 Billion (augmented network) to proceed immediately with deployment of ATMS in the largest 75 metropolitan areas. Costs are given in 1992 dollars, and are not adjusted for future inflation. Our estimates are based partially on completed project costs, which have been adjusted to 1992 dollars. We assume that a particular architecture will be chosen; projected costs are broken out by architecture. Costs are divided among areas by population as shown in Tables 3-4. Total cost per year is shown in Tables 5-6.

Approach

For this report, we have requested information about the component costs of ATMS or IVHS projects from a number of sources (see References and Sources) representing various sizes of metropolitan areas. The numbers from different sources were compared, and unit costs were estimated. Using available data for metropolitan area populations and highway mileages, total cost projections were computed for each of the 75 largest metropolitan areas. The estimated area costs were summed within each size category and across categories to give the overall cost estimate. The calculations were repeated for various assumptions about highway networks and IVHS architectures.

For this report, we have collected data from a number of areas. Those data allow us to adjust our estimates to account for geographical differences in costs, and to take into account the current state of operation, construction, or planning within some of the specific areas considered. We have projected costs by summing what we do know and extrapolating cost numbers for areas for which we do not have complete data.

We also base our estimates on the following assumptions:

General Assumptions

- The architectural options are those identified in the MITRE Corp. Working Paper 91-W-00512, Alternative IVHS Architectures as Strawman Architectures 1-4. The options are summarized in Table 2.
- Only infrastructure components are included. In-vehicle components are specifically excluded.
- For this report, highway centerline mileages (both directions of travel) for the metropolitan areas were derived from the Federal Highway Administration's (FHWA's) Highway Performance Monitoring System. We have considered two highway networks for our estimates. The lowest-cost configuration considers freeways and only the set of arterials that could be major diversion routes within a metropolitan area, which we call the minimal network. For the second network, we include also many of the remaining arterials within the metropolitan area, under the supposition that traffic would be monitored and signals controlled within the entire freeway and arterial network by the

ATMS. The second network is referred to as the augmented network, but it still excludes signalized intersections on less-important streets within an area. If our other assumptions are accurate, calculations based on the minimal network and on the augmented network may represent practical lower and upper bounds on the required funds. Projects now in active planning stages for which we obtained data usually consider networks no larger than our minimal networks. We exercised some engineering judgement in assigning numbers of miles of arterials to metropolitan areas, since details of reasonable ATMS project scope will be specific to each area. Further discussion of highway mileages is included in the final section of this report.

- We assume interchange spacing on freeways to be two miles.
- Reviewers of a draft of this report suggested a five-mile spacing for variable-message signs. We have used that number, even though one active ATMS design has somewhat more dense spacing. If signs were paired, for example, with one sign for each direction of travel near a critical interchange, the five-mile average spacing would be consistent with ten-mile critical-interchange spacing.
- As discussed in the MITRE paper, each architecture includes traffic sensors along freeways and arterials, a communication network linking the sensors to a traffic management center, variable message signs (and, in two architectures, beacons) at strategic locations along the highway network, traffic control devices at ramps and intersections (assumed to be coordinated within an area), and a computer system adequate to analyze the collected data and disseminate the required guidance and control information. Three of the four strawman architectures include one- or two-way radio communication between vehicles and the infrastructure. Some features of the architectures are given in the MITRE paper.
- For this report, traffic sensors are assumed to be inductive loops, the communication trunks are assumed to be fiber optic cables, and the computer facility is assumed to be a network made up of front-end data acquisition computers, one or more central computation/database servers, and workstations for operator interaction.
- Software cost is based on estimates from firms that now supply such software. No allowance is made for either Federal government development of generic software or a significant third-party software development effort, although the cost of software considerably exceeds the cost of hardware.

- Deployment is assumed to "ramp up." That is, larger projects will begin by next year, with many smaller projects phasing in over the five-year period. The projects will have multi-year duration, with larger projects of course taking somewhat longer than small ones, though not proportionally longer, since presumably more intensive effort will be expended on the larger ones. Our estimates assume that efforts will be well under way in all 75 metropolitan areas by the end of the five-year period.

Assumed Component Costs

Planning, engineering, and design are assumed to be required in proportion to the expected total project size. Our assumed costs are based partly on the engineering judgement of our consultants. For this interim report we assume planning is 5%-10% complete for large metropolitan areas, and not significantly begun for mid-sized and smaller areas.

Sensor hardware is assumed to be inductive loops with moderately intelligent controller/interfaces, installed at 0.3-mile intervals in each direction of travel for freeways and at intersections for arterials. Installed cost per mile is assumed to be \$50K, a figure between those usually quoted for southern and northern regions of the country. (We believe that sensor technology other than inductive loops might give a significant improvement in benefit/cost performance within the period under consideration. If development of image-processing hardware and algorithms solves the remaining ambient-light problems, it will be possible to use video for the more mundane traffic-counting functions, with low-bandwidth count data reporting requirements. The same cameras will then be widely available for high-bandwidth incident detection/verification, a concept that one consultant calls "video-on-demand." Both cameras and image-processing hardware are participants in the on-going cost reduction process for solid state equipment, and the installed cost of a camera and controller may well be less than the installed cost of an inductive loop and controller within the time frame of ATMS deployment.)

Variable-message signs (VMS) are used or proposed in several projects for which we have some cost information. We assume that variable message signs will be spaced about every five miles on freeways, and extrapolate our sign-cost data to give an installed cost of \$40K/mile. (In urban areas with well-developed highway networks, where opportunities for alternate routes occur more often than every five miles, it is possible that VMS spacing will be less than five miles.) Ramp metering signals are assumed to be used extensively, at a cost of \$30K/mile. Replacement cost for obsolete intersection

signals is likely to be significant. We have guessed that half the traffic signals now in use would need to be replaced or upgraded. Costs are included below for extensive cabling to connect the signals into an ATMS.

Beacons for two-way communications between the infrastructure and vehicles are features of Architectures 2 and 4. Installed cost projections for beacon hardware are somewhat speculative. (We considered costs from a proposed project that uses beacons, but asked our consultants to evaluate our preliminary estimates.) We assume beacons at 0.5 mile intervals along freeways and principal arterials, and guess the cost to be \$50K/mile. Note that using beacons presumes high-speed communication or very clever coding of information, and that beacon cost is one differentiating feature among the MITRE architectures.

Three architectures assume radio communication between vehicles and the infrastructure. The infrastructure components required are estimated to cost \$15K/mile (Architectures 1, 2, and 3), with associated installation and maintenance costs. Radio broadcasting can cover an area, as opposed to being a linear process aligned with a roadway. That reduces the number of transmitters required to cover a highway network. However, there are several potential radio technologies that could be utilized, and the MITRE architecture discussions leave great freedom to choose a particular broadcast technique, with its associated costs. Accordingly, our numbers here are not very conclusive; we expect that further architecture studies will enable better cost estimates for this function. In any case, we doubt that radio-broadcast equipment will be a cost driver in any ATMS architecture that is ultimately chosen for implementation.

Sensors and signals for an ATMS are assumed to be linked into a network by a communication trunk line with interfaces and local links at individual locations. We assume that very little of the required communication network is now in place. We assume fiber optic cable in conduit, because fiber optic cable offers orders of magnitude more capability for transmitting information than twisted-pair cable. Recent experience and several studies indicate that fiber optics is becoming available at little extra cost, and use of fiber optics will provide enough bandwidth to effectively "future-proof" the communication network for the foreseeable future. Several reputable experts suggested that we consider geographical differences in the cost of installing conduit, which dominates the communication trunk cost. Installed cost per mile for cable is assumed to be \$125K - \$175K; both figures are within the range quoted for different climates and areas. As one can see from the graph on page 5 of the estimation model in the

appendix, the cost of providing such a conduit/cable communication network dominates the overall system installation costs. Since data collection is common to all proposed ATMS architectures, the cost dominance of the communications (actually, the cost of installing conduit) tends to minimize variations in our cost estimates for different architectures. We assume a distributed traffic management architecture, which is usually assumed to require lower overall communication cost than a strongly centralized system.

The cost of computer hardware cannot be projected reliably from costs on record for projects now in successful operation, because of the remarkably rapid increase in computational power per dollar, for which the computer industry is justly famous. We consider instead, the computational power and user interfaces required for recent ORNL projects, such as the AMC Deployment Analysis System project for the Airlift Mobility Command, which perform somewhat similar (and similarly difficult) functions. We assume a modular, fault-tolerant client-server architecture, where a module consists of a network of small data-acquisition/concentration computers, perhaps some multiplexer or concentrator computers, one or a few computation or database server(s), and three to five client workstations for operators. The data-handling computers for a such a modular Traffic Management Center (TMC) and the operator workstations are assumed to be linked in a high-availability local area network. Modules within a large metropolitan area are assumed to be linked by a wide area network. Projected cost is somewhat sensitive to whether the route-planning function is carried out in the vehicle or in the TMC computers, but installed cost of such a system is unlikely to be significantly more than \$175K per module. Other (e.g., mini-computer-based) computer hardware could be selected if different criteria such as backward compatibility with existing software were a dominant consideration or if a strongly centralized system were chosen, but it is unlikely that ATMS architectures now under consideration will need more expensive hardware to realize full functionality.

Recent experience suggests that computer equipment often is obsolete before it fails, and that it has an effective lifetime of no more than five years. Computer equipment upgrades can be considered to be an annual "maintenance" cost of about \$30K per module per year.

One module should serve a small metropolitan (or equivalent) area, but the actual number and location of TMCs in a metropolitan area are likely to be influenced by the political boundaries within the area. However, because we have no reasonable basis for second-guessing politicians, we have assumed that TMCs will be distributed by traffic

requirements related to population, and that a TMC will serve about half a million people. By these criteria, at least one TMC will be required in each area, and the requirements will scale up to more than a dozen distributed throughout an area such as the greater New York area.

The development of unique ATMS software for each metropolitan area does not seem to us to be justified by differences in requirements. We therefore assume that the one-time cost for design and development of the basic software is distributed over at least several sites. The resulting cost per module, \$300K, is based on estimates provided by two vendors of such software. Basic software cost should not be very specific to size of the area, but the cost of creating the site-specific highway network data base is; we include a per-mile cost for "instantiation" of the software. There is also a recurring cost of \$15K per year for software maintenance and upgrading.

Our consultants suggest that regional traffic management centers -- the modules discussed above -- could occupy about 1000 square feet of building space, perhaps with a larger central coordinating site in the largest metropolitan areas. (This space requirement contains a tacit assumption that traffic management within larger metropolitan areas will be distributed among the local districts within the area. If the local governments within a large area choose to consolidate all management functions in a single central traffic management center, a decision strongly influenced by the chosen IVHS architecture, several cost categories would be influenced. Our consultants suggest that most, if not all, of their new systems are likely to be modular and distributed. Current practice and trends in other computer-based business and control domains suggest a strong and increasing tendency toward distributing functionality.) Projects for which we received cost data tended to spend millions of dollars constructing new buildings. We do not believe that large central facilities are technically justified, and have assumed a distributed system, with an initial cost per local TMC of \$200K, with a continuing yearly cost of \$20K. These figures might represent the cost of adapting existing office space which is thereafter leased.

Successful deployment of advanced traffic management systems will require the creation of a cadre of well-trained professionals who are familiar with and proficient at traffic management, and are also comfortable with and capable of using and maintaining the computer-based advanced technology of the future Traffic Management Center. After visiting several existing showcase TMCs, we estimated that -- ideally -- each TMC module will require three operators per rush hour shift, one hardware maintenance

expert, and one software maintenance expert. That staffing level translates roughly into salary cost of \$750K per year. However, our consultants indicate that they believe that few metropolitan areas are really likely to staff at that level. The estimates of recurring cost in this report are accordingly based on our experts' suggestion of about \$400K per year per local TMC. (Using the larger figure -- with three operators instead of two, and an additional support staff member -- increases operating costs by about 5 per cent.) Large, multi-shift TMC operations can realize economies of scale by using fewer maintenance personnel and very small operations might combine the hardware and software maintenance functions into a single position or share maintenance staff with other municipal functions, but every physically distinct site will require some maintenance staffing.

Discussion of Computational Procedures and Methods

Computational Procedures

Summary costs were computed from the component data by the procedures shown in the attached MathCAD™ model. Individual metropolitan area costs were estimated for each highway network configuration paired with each architectural option, considering all of the available data about status of current plans, geographically significant cost variations, and unique metropolitan area needs. The resulting individual estimates were then summed for overall projected costs.

The time distribution of costs was projected by assuming a forward-skewed time-cost distribution for each project (an example is plotted in the Appendix) , assuming that larger projects take longer, and that project start dates will be distributed over the next two years (details are in the MathCAD model). The calculated distributions of individual project costs were then summed to give an overall distribution of costs.

Precision, Accuracy, and Range of Applicability

It became apparent to us almost as soon as we began to collect cost data that there was great variability in cost reports and cost estimates for similar work. We believe -- as do our consultants -- that the variability results both from actual variation in costs, and from great variability in reporting/estimating costs (for whatever technical or political realities). Accordingly, we have made our projections based on "reasonable compromise" unit costs that fall within the reported and estimated numbers. Hence our

projections are "reasonable" extrapolations, and should not be compared directly to the actual costs or estimates for any specific project. Component cost assumptions are listed in Table 7.

In addition, we realize that there are many combinations of components that could be implemented as ATMS and that costs for the components will vary according to forces in the market place. We have therefore built a fairly general model that can be used to project costs for any chosen set of components, as long as unit data are available or can be estimated, and as long as some assumptions can be made about the placement of elements on the highway network.

For each element of cost, the reported or estimated unit cost typically varied by at least a factor of two. We therefore have not made any corrections to our projections to account for "small" effects like inflation.

Opportunities for Further Efforts

Response to Definition of Architectures

Our model has been constructed to allow revised project scope and unit cost data to be entered when such data become available. In particular, as IVHS architectures become more fully defined, it will become easier to differentiate between suggested configurations and the essential components of each architecture will be known. As unit costs for those components are determined, it will be possible to better estimate the cost of implementation of a particular configuration in a specific situation. Such an estimate, of course, is no substitute for a complete engineering study, but our model could provide useable rough estimates as the scope of potential projects is considered.

Refinement of Mileage Estimates

Metropolitan statistical area classification is a statistical standard, developed for use by Federal agencies in the production, analysis, and publication of data on metropolitan areas. Three basic types of metropolitan areas are recognized by the Office of Management and Budget (OMB) for Federal Statistical purposes: metropolitan statistical areas (MSAs), consolidated metropolitan statistical areas (CMSAs), and primary metropolitan statistical areas (PMSAs).

A metropolitan statistical area is a geographic area consisting of a large population nucleus (i.e., census-defined urban area) along with adjacent communities that have a high degree of economic and social integration with the nucleus. Each MSA contains one or more central counties which contain the area's main population concentration. An MSA may also include outlying counties that have close social and economic interaction with the central county. However, such outlying counties must have a specified population density and level of commuting with the central counties. If an area has more than one million residents and meets specified population and commuting criteria, PMSAs may be identified. PMSAs consist of a large urbanized county or cluster of counties that have strong internal economic and social links, in addition to close ties to neighboring areas. Local opinion must also support separate recognition of PMSAs. Unlike MSAs, PMSAs do not have to have a central city. When PMSAs are defined, the MSA of which they are components is redesignated as a CMSA.

The list of metropolitan areas to be included in this project was provided by the Federal Highway Administration. This list consists mostly of MSAs and CMSAs. Unfortunately, many of these regions contain large areas that are not populous enough to warrant the implementation of Advanced Traffic Management Systems. Thus, to estimate the cost of implementing ATMS for such sparsely populated areas seemed to us not to be within the scope of this project. To support this position, the following two examples are given.

The Montgomery MSA in Alabama includes Autauga, Elmore, and Montgomery counties. The City of Montgomery, located in Montgomery County, has more than 100,000 residents. However, neither Autauga nor Elmore county has a single city with a population of more than 25,000. Thus, it seems unlikely that the highways, expressways, and arterials in these two counties would be included in ATMS projects.

The Los Angeles-Anaheim-Riverside CMSA includes the Anaheim-Santa Ana, Los Angeles-Long Beach, Oxnard-Ventura, and Riverside-San Bernardino PMSAs. The Riverside-San Bernardino PMSA extends all the way to the Arizona and Nevada state boundaries. Although the cities of San Bernardino and Riverside have more than 100,000 residents, much of the PMSA has a small population, and a significant portion of this PMSA lies within the desert. Thus, it seems unlikely that ATMS of the nature considered in this study would be implemented in these areas.

Therefore, in order to minimize the effects of including such large areas with relatively small populations, those urban areas having more than 100,000 residents as defined by individual states and reported in the HPMS were used to estimate the highway mileage for future IVHS projects.

The Highway Performance Monitoring System (HPMS), developed by the Federal Highway Administration, is a program management tool used to periodically assess the national highway system in terms of extent and physical condition; the safety, efficiency, and economy of the system in serving the movement of goods and people; and the impacts of existing national programs and policies. HPMS is also used to assess the potential impacts of proposed programs, policies, and alternatives. The system promotes the efficient use of decreasing financial resources and provides invaluable information to decision makers.

This study provides the FHWA with a preliminary estimate of the costs involved in implementing ATMS projects in urban areas. The estimates are based on average costs per mile and highway mileage estimates for plausible networks in the major metropolitan areas.

It seems desirable to have a system that would be capable of tracking summary cost estimates for the major metropolitan areas by allowing entry of data about the kinds of technologies to be used and the exact expressway and arterial sections as they are chosen for ATMS system design. We believe that a minimal geographically linked database could be developed to accurately track estimates of the cost of implementing ATMS and/or other IVHS-related systems. Such summary estimates of course would not be a substitute for preliminary engineering design, but they could be extremely useful both to administrators of a national program, and to local decision-makers who need to prepare budget estimates for the political review process.

Table 1. Metropolitan Areas Ordered by Population

New York	1	Sacramento	26	Honolulu	51
Los Angeles	2	Portland	27	Austin	52
Chicago	3	Norfolk	28	Las Vegas	53
San Francisco	4	Columbus OH	29	Raleigh-Durham	54
Philadelphia	5	San Antonio	30	Scranton	55
Detroit	6	Indianapolis	31	Tulsa	56
Boston	7	New Orleans	32	Grand Rapids	57
Dist of Columbia	8	Buffalo	33	Allentown	58
Dallas-FtWorth	9	Charlotte	34	Fresno	59
Houston	10	Providence	35	Tucson	60
Miami	11	Hartford	36	Syracuse	61
Atlanta	12	Orlando	37	Greenville SC	62
Cleveland	13	Salt Lake City	38	Omaha	63
Seattle	14	Rochester	39	Toledo	64
San Diego	15	Nashville	40	Knoxville	65
Minneapolis	16	Memphis	41	El Paso	66
St Louis	17	Oklahoma City	42	Harrisburg	67
Baltimore	18	Louisville	43	Bakersfield	68
Pittsburgh	19	Dayton	44	New Haven	69
Phoenix	20	Greensboro-WS	45	Springfield MA	70
Tampa	21	Birmingham	46	Baton Rouge	71
Denver	22	Jacksonville	47	Little Rock	72
Cincinnati	23	Albany	48	Charleston	73
Milwaukee	24	Richmond	49	Youngstown	74
Kansas City	25	West Palm Beach	50	Wichita	75

Table 2. Summary Comparison of MITRE Architectures

[Derived directly from Table 3.2 of MITRE Report]

Architecture 1:

- Uncoupled route selection/traffic control
- In-vehicle route selection
- In-vehicle map database
- Two-way wide-area radio communications

Architecture 2:

- Partially coupled route selection/traffic control
- In-vehicle route selection
- In-vehicle map database
- Two-way localized (beacon) communications

Architecture 3:

- Fully coupled route selection/traffic control
- Centralized route selection (with real-time data)
- In-vehicle route selection (with static data) when real-time routing is unavailable
- In-vehicle map database
- Two-way cellular radio communications (digital technology)
- One-way traffic information broadcast to vehicles

Architecture 4:

- Uncoupled route selection/traffic control
- Centralized route selection
- No in-vehicle map database
- Two-way localized (beacon) communications

**Table 3. Projected Total ATMS Cost by Architecture and Metro Area Size
(Minimal highway network)**

	Arch 1	Arch 2	Arch 3	Arch 4
9 Regions with population > 4M	\$3.81B	\$4.4B	\$3.82B	\$4.41B
O&M per year	\$276M	\$335M	\$277M	\$335M
12 Regions with 2M< pop <4M	\$1.91B	\$2.24B	\$1.91B	\$2.25B
O&M per year	\$143M	\$176M	\$144M	\$177M
18 Regions with 1M< pop <2M	\$1.51B	\$1.75B	\$1.52B	\$1.76B
O&M per year	\$114M	\$138M	\$115M	\$139M
36 Regions with pop < 1M	\$1.33B	\$1.56B	\$1.34B	\$1.56B
O&M per year	\$103M	\$125M	\$103M	\$125M
Total Installed Cost	\$8.57B	\$9.95B	\$8.59	\$9.97B
Total Annual O&M	\$640M	\$770M	\$640M	\$780M

**Table 4. Projected Total ATMS Cost by Architecture and Metro Area Size
(Augmented highway network)**

	Arch 1	Arch 2	Arch 3	Arch 4
9 Regions with population > 4M	\$10.9B	\$11.5B	\$10.9B	\$11.5B
O&M per year	\$710M	\$768M	\$710M	\$769M
12 Regions with 2M< pop <4M	\$5.45B	\$5.79B	\$5.46B	\$5.79B
O&M per year	\$367M	\$400M	\$368M	\$401M
18 Regions with 1M< pop <2M	\$4.31B	\$4.45B	\$4.32B	\$4.55B
O&M per year	\$289M	\$313M	\$289M	\$313M
36 Regions with pop < 1M	\$3.8B	\$4.03B	\$3.81B	\$4.03B
O&M per year	\$258M	\$281M	\$259M	\$281M
Total Installed Cost	\$24.46B	\$25.84B	\$24.48B	\$25.86B
Total Annual O&M	\$1.62B	\$1.76B	\$1.63B	\$1.76B

**Table 5. Projected Total ATMS Cost by Architecture and Year
(Minimal highway network)**

	Arch 1	Arch 2	Arch 3	Arch 4
FY93 Capital	\$0.97B	\$1.12B	\$0.97B	\$1.12B
FY94 Capital	\$2.03B	\$2.35B	\$2.03B	\$2.36B
FY95 Capital	\$2.65B	\$3.08B	\$2.66B	\$3.09B
FY96 Capital	\$2.03B	\$2.36B	\$2.04B	\$2.37B
FY97 Capital	\$0.89B	\$1.03B	\$0.89B	\$1.03B
Total Capital	\$8.57B	\$9.95B	\$8.59B	\$9.97B

**Table 6. Projected Total ATMS Cost by Architecture and Year
(Augmented highway network)**

	Arch 1	Arch 2	Arch 3	Arch 4
FY93 Capital	\$2.78B	\$2.93B	\$2.78B	\$2.93B
FY94 Capital	\$5.79B	\$6.12B	\$5.79B	\$6.12B
FY95 Capital	\$7.56B	\$8.0B	\$7.57B	\$8.0B
FY96 Capital	\$5.8B	\$6.13B	\$5.8B	\$6.13B
FY97 Capital	\$2.53B	\$2.67B	\$2.53B	\$2.68B
Total Capital	\$24.46B	\$25.84B	\$24.48B	\$25.86B

Table 7. Assumed Component Unit Costs

Component of Cost	Assumed Value			
	Arch 1	Arch 2	Arch 3	Arch 4
Planning and Engineering		<== 10% of project cost ==>		
Traffic Sensors		<== \$50K/mi ==>		
Signals and Controllers		<== \$40K/int ==>		
Variable Message Signs		<== \$40K/mi ==>		
Beacons	0	\$50K/mi	0	\$50K/mi
Radio	\$15K/mi	\$15K/mi	\$15K/mi	0
Communication Lines		<== \$150K/mi ==>		
Computer Hardware	\$125K/mod	\$125K/mod	\$175K/mod	\$150K/mod
Computer Software		<== \$300K/mod ==>		
Staff		<== \$400K/yr ==>		
Building Space		<== \$200K/mod ==>		

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We are especially grateful to our consultants, Craig Gardner of JHK Associates, and Phil Tarnoff of Farradyne Systems.

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Background sources

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APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i := 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j := 0..11$

element 0 is planning and engineering cost,
element 1 is sensor cost,
element 2 is signal cost,
element 3 is variable-message sign cost,
element 4 is beacon cost (which will be 0 in some architectures),
element 5 is radio cost (which will be 0 in some architectures),
element 6 is communication 'cabling' cost,
element 7 is computer hardware original cost,
element 8 is computer software original cost,
element 9 is staff cost,
element 10 is cost of providing building space, and
element 11 is 'other' — to be defined — cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$

Population, in thousands

$\text{Modules}_i := \text{ceil}\left(\frac{\text{Pop}_i}{10^3}\right)$

Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$

Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$

Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2),5}$

Number of (augmented) arterial miles

$\text{Aug} := 0$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$

Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$

Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$

Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 1

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

$$\text{SignalCostPerIntersect} := 40 \cdot K$$

$$\text{SensorCostPerMile} := 50 \cdot K$$

$$Fr_{old} := 0.5$$

$$\text{VMSCostPerMile} := 40 \cdot K$$

$$\text{BeaconCostPerMile} := 0 \cdot K$$

$$\text{RadioCostPerMile} := 15 \cdot K$$

$$\text{CommCostPerMile} := 150 \cdot K$$

$$\text{CompHdweCostPerModule} := 125 \cdot K$$

$$\text{SoftweInstanceCostPerMile} := 2 \cdot K$$

$$\text{StaffCostPerModule} := 400 \cdot K$$

$$\text{BuildingCostPerModule} := 200 \cdot K$$

$$\text{SoftweOrigCostPerModule} := 300 \cdot K$$

$$\text{OtherCostPerMile} := 0$$

$$\text{SoftweUpdateCostPerModule} := 15 \cdot K$$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

$$\text{ElementCost}_{(1,0)} := 0 \quad (\text{will add in as 10\% after calculation of capital cost})$$

$$\text{ElementCost}_{1,1} := \text{SensorCostPerMile} \cdot \text{StatusFactor}_1 \cdot \text{GeoFactor}_1 \cdot \text{TotM}_1 \cdot K$$

$$\text{ElementCost}_{1,2} := \text{SignalCostPerIntersect} \cdot \left(\frac{\text{Intersect}_1 \cdot Fr_{old} + \text{FwyM}_1}{1} \right) \cdot K$$

$$\text{ElementCost}_{1,3} := \text{VMSCostPerMile} \cdot \text{FwyM}_1 \cdot \text{GeoFactor}_1 \cdot \text{StatusFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,4} := \text{BeaconCostPerMile} \cdot \left[(\text{FwyM}_1 + \text{MinArtM}_1) \cdot K \right]$$

$$\text{ElementCost}_{1,5} := \text{RadioCostPerMile} \cdot \text{FwyM}_1 \cdot K$$

$$\text{ElementCost}_{1,6} := \text{CommCostPerMile} \cdot \text{TotM}_1 \cdot \text{GeoFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,7} := \text{CompHdweCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,8} := \text{SoftweInstanceCostPerMile} \cdot \text{TotM}_1 \cdot K + (\text{SoftweOrigCostPerModule} \cdot \text{Modules}_1)$$

$$\text{ElementCost}_{1,9} := \text{StaffCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,10} := \text{BuildingCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{(1,11)} := \text{OtherCostPerMile} \cdot K$$

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} := \text{InstalledCost}_i \cdot 0.1$$

Considering engineering as 10% of capital cost

74

SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 3.81 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 1.91 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 1.51 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 1.33 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

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For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' — to be defined — cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} := \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 8.57 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area — for maintenance — and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots$$

$$+ 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,6}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,6}$$

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SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 275.77 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 143.17 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 114.42 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 102.61 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 0.64 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr = 0..19

and index the area sizes by k, where

k = 0..3 ('0' is largest)

Recall that

$K = 1$

$M = 1 \cdot 10^3 \cdot K$

$B = 1 \cdot 10^3 \cdot M$

LargeAreaCost = $3.81 \cdot B$

and

MediumLargeAreaCost = $1.91 \cdot B$

MediumSmallAreaCost = $1.51 \cdot B$

SmallAreaCost = $1.33 \cdot B$

Then $QtrCost_{qtr,0} = TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} := TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} := TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} := TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr = 0..4$$

$$AnnualCost_0 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 0.97 \cdot B$$

$$AnnualCost_1 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 2.03 \cdot B$$

$$AnnualCost_2 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 2.65 \cdot B$$

$$AnnualCost_3 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 2.03 \cdot B$$

$$AnnualCost_4 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 0.89 \cdot B$$

As a check,

$$SumOfCost := \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 8.57 \cdot B$$

$$GrandTotalCapital = 8.57 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' — to be defined — cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{ceil}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 1$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$
Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing
construction costs by climate and differing
intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and
implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 1

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

$$\text{SignalCostPerIntrsect} = 40 \cdot K$$

$$\text{SensorCostPerMile} = 50 \cdot K$$

$$Fr_{old} = 0.5$$

$$\text{VMSCostPerMile} = 40 \cdot K$$

$$\text{BeaconCostPerMile} = 0 \cdot K$$

$$\text{RadioCostPerMile} = 15 \cdot K$$

$$\text{CommCostPerMile} = 150 \cdot K$$

$$\text{CompHdweCostPerModule} = 125 \cdot K$$

$$\text{SoftweInstanceCostPerMile} = 2 \cdot K$$

$$\text{StaffCostPerModule} = 400 \cdot K$$

$$\text{BuildingCostPerModule} = 200 \cdot K$$

$$\text{SoftweOrigCostPerModule} = 300 \cdot K$$

$$\text{OtherCostPerMile} = 0$$

$$\text{SoftweUpdateCostPerModule} = 15 \cdot K$$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

$$\text{ElementCost}_{(1,0)} = 0 \quad (\text{will add in as 10\% after calculation of capital cost})$$

$$\text{ElementCost}_{1,1} = \text{SensorCostPerMile} \cdot \text{StatusFactor}_1 \cdot \text{GeoFactor}_1 \cdot \text{TotMi}_1 \cdot K$$

$$\text{ElementCost}_{1,2} = \text{SignalCostPerIntrsect} \cdot \left(\frac{\text{Intrsect}_1 \cdot Fr_{old} + FwyMi_1}{\text{Intrsect}_1 \cdot Fr_{old} + FwyMi_1} \right) \cdot K$$

$$\text{ElementCost}_{1,3} = \text{VMSCostPerMile} \cdot FwyMi_1 \cdot \text{GeoFactor}_1 \cdot \text{StatusFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,4} = \text{BeaconCostPerMile} \cdot [(FwyMi_1 + \text{MinArtMi}_1) \cdot K]$$

$$\text{ElementCost}_{1,5} = \text{RadioCostPerMile} \cdot FwyMi_1 \cdot K$$

$$\text{ElementCost}_{1,6} = \text{CommCostPerMile} \cdot \text{TotMi}_1 \cdot \text{GeoFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,7} = \text{CompHdweCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,8} = \text{SoftweInstanceCostPerMile} \cdot \text{TotMi}_1 \cdot K + (\text{SoftweOrigCostPerModule} \cdot \text{Modules}_1)$$

$$\text{ElementCost}_{1,9} = \text{StaffCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,10} = \text{BuildingCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{(1,11)} = \text{OtherCostPerMile} \cdot K$$

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i = \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i = \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} = \text{InstalledCost}_i \cdot .1$$

Considering engineering as 10% of capital cost

74

SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 10.89 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 5.45 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 4.31 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 3.8 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

11

For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' — to be defined — cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} := \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 24.46 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area — for maintenance — and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i = \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots$$

$$+ 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,8}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,8}$$

74

SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 709.53 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 367.31 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 288.9 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 258.2 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 1.62 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr = 0..19

and index the area sizes by k, where

k = 0..3 ('0' is largest)

Recall that

K = 1

M = $1 \cdot 10^3 \cdot K$

B = $1 \cdot 10^3 \cdot M$

LargeAreaCost = $10.89 \cdot B$

and

MediumLargeAreaCost = $5.45 \cdot B$

MediumSmallAreaCost = $4.31 \cdot B$

SmallAreaCost = $3.8 \cdot B$

Then

$QtrCost_{qtr,0} = TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} = TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} = TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} = TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr = 0..4$$

$$AnnualCost_0 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 2.78 \cdot B$$

$$AnnualCost_1 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 5.79 \cdot B$$

$$AnnualCost_2 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 7.56 \cdot B$$

$$AnnualCost_3 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 5.8 \cdot B$$

$$AnnualCost_4 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 2.53 \cdot B$$

As a check,

$$SumOfCost := \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 24.46 \cdot B$$

$$GrandTotalCapital = 24.46 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' -- to be defined -- cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{cell}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 0$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$
Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 2

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

SignalCostPerIntersect := 40 · K

SensorCostPerMile := 50 · K

Fr_{old} := 0.5

VMSCostPerMile := 40 · K

BeaconCostPerMile := 50 · K

RadioCostPerMile := 15 · K

CommCostPerMile := 150 · K

CompHdweCostPerModule := 125 · K

SoftweInstanceCostPerMile := 2 · K

StaffCostPerModule := 400 · K

BuildingCostPerModule := 200 · K

SoftweOrigCostPerModule := 300 · K

OtherCostPerMile := 0

SoftweUpdateCostPerModule := 15 · K

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

ElementCost_(1,0) := 0 (will add in as 10% after calculation of capital cost)

ElementCost_{1,1} := SensorCostPerMile · StatusFactor₁ · GeoFactor₁ · TotMi₁ · K

ElementCost_{1,2} := SignalCostPerIntersect · $\left(\frac{\text{Intersect}_1 \cdot \text{Fr}_{\text{old}} + \text{FwyMi}_1}{\text{FwyMi}_1} \right) \cdot K$

ElementCost_{1,3} := VMSCostPerMile · FwyMi₁ · GeoFactor₁ · StatusFactor₁ · K

ElementCost_{1,4} := BeaconCostPerMile · $\left[\left(\text{FwyMi}_1 + \text{MinArtMi}_1 \right) \cdot K \right]$

ElementCost_{1,5} := RadioCostPerMile · FwyMi₁ · K

ElementCost_{1,6} := CommCostPerMile · TotMi₁ · GeoFactor₁ · K

ElementCost_{1,7} := CompHdweCostPerModule · Modules₁ · K

ElementCost_{1,8} := SoftweInstanceCostPerMile · TotMi₁ · K + (SoftweOrigCostPerModule · Modules₁)

ElementCost_{1,9} := StaffCostPerModule · Modules₁ · K

ElementCost_{1,10} := BuildingCostPerModule · Modules₁ · K

ElementCost_(1,11) := OtherCostPerMile · K

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} := \text{InstalledCost}_i \cdot 1$$

Considering engineering as 10% of capital cost

SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 4.4 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 2.24 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 1.75 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 1.56 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' - to be defined - cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} = \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 9.95 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area – for maintenance – and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i = \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots \\ + 0.1 \cdot \left(\text{CapitalCost}_i - \text{ElementCost}_{i,s} \right) + 0.03 \cdot \text{ElementCost}_{i,s}$$

SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 334.62 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 176.33 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 138.29 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 125.05 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 0.77 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist.prn)

Index the data by quarters, where

qtr := 0..19

and index the area sizes by k, where

k := 0..3 ('0' is largest)

Recall that $K = 1$ $M = 1 \cdot 10^3 \cdot K$ $B = 1 \cdot 10^3 \cdot M$

LargeAreaCost = $4.4 \cdot B$

and

MediumLargeAreaCost = $2.24 \cdot B$

MediumSmallAreaCost = $1.75 \cdot B$

SmallAreaCost = $1.56 \cdot B$

Then $QtrCost_{qtr,0} := TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} := TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} := TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} := TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr := 0..4$$

$$\text{AnnualCost}_0 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr < 4)$$

$$\text{AnnualCost}_0 = 1.12 \cdot B$$

$$\text{AnnualCost}_1 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$\text{AnnualCost}_1 = 2.35 \cdot B$$

$$\text{AnnualCost}_2 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$\text{AnnualCost}_2 = 3.08 \cdot B$$

$$\text{AnnualCost}_3 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$\text{AnnualCost}_3 = 2.36 \cdot B$$

$$\text{AnnualCost}_4 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 15)$$

$$\text{AnnualCost}_4 = 1.03 \cdot B$$

As a check,

$$\text{SumOfCost} := \sum_{yr} \text{AnnualCost}_{yr}$$

$$\text{SumOfCost} = 9.95 \cdot B$$

$$\text{GrandTotalCapital} = 9.95 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i := 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j := 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' — to be defined — cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{ceil}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 1$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$
Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 2

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

SignalCostPerIntrsect := 40 · K

SensorCostPerMile = 50 · K

Fr_{old} := 0.5

VMSCostPerMile = 40 · K

BeaconCostPerMile := 50 · K

RadioCostPerMile := 15 · K

CommCostPerMile := 150 · K

CompHdweCostPerModule := 125 · K

SoftweInstanceCostPerMile := 2 · K

StaffCostPerModule := 400 · K

BuildingCostPerModule := 200 · K

SoftweOrigCostPerModule := 300 · K

OtherCostPerMile := 0

SoftweUpdateCostPerModule = 15 · K

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

ElementCost_(1,0) := 0 (will add in as 10% after calculation of capital cost)

ElementCost_{1,1} := SensorCostPerMile · StatusFactor_i · GeoFactor_i · TotMi_i · K

ElementCost_{1,2} := SignalCostPerIntrsect · $\left(\overrightarrow{(\text{Intrsect}_i \cdot \text{Fr}_{\text{old}} + \text{FwyMi}_i)} \right) \cdot K$

ElementCost_{1,3} := VMSCostPerMile · FwyMi_i · GeoFactor_i · StatusFactor_i · K

ElementCost_{1,4} := BeaconCostPerMile · $\left[(\text{FwyMi}_i + \text{MinArtMi}_i) \cdot K \right]$

ElementCost_{1,5} := RadioCostPerMile · FwyMi_i · K

ElementCost_{1,6} := CommCostPerMile · TotMi_i · GeoFactor_i · K

ElementCost_{1,7} := CompHdweCostPerModule · Modules_i · K

ElementCost_{1,8} := SoftweInstanceCostPerMile · TotMi_i · K + (SoftweOrigCostPerModule · Modules_i)

ElementCost_{1,9} := StaffCostPerModule · Modules_i · K

ElementCost_{1,10} := BuildingCostPerModule · Modules_i · K

ElementCost_(1,11) := OtherCostPerMile · K

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(1,0)} := \text{InstalledCost}_1 \cdot 1$$

Considering engineering as 10% of capital cost

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SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 11.48 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 5.79 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 4.55 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 4.03 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' - to be defined - cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} = \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 25.84 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area – for maintenance – and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots \\ + 0.1 \cdot \left(\text{CapitalCost}_i - \text{ElementCost}_{i,g} \right) + 0.03 \cdot \text{ElementCost}_{i,g}$$

SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 768.38 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 400.47 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 312.77 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 280.64 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 1.76 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

$\text{TimeCoeffs} := \text{READPRN}(\text{timedist.prn})$

Index the data by quarters, where

$\text{qtr} := 0..19$

and index the area sizes by k, where

$k := 0..3$ ('0' is largest)

Recall that

$K = 1$

$M = 1 \cdot 10^3 \cdot K$

$B = 1 \cdot 10^3 \cdot M$

$\text{LargeAreaCost} = 11.48 \cdot B$

and

$\text{MediumLargeAreaCost} = 5.79 \cdot B$

$\text{MediumSmallAreaCost} = 4.55 \cdot B$

$\text{SmallAreaCost} = 4.03 \cdot B$

Then $\text{QtrCost}_{\text{qtr},0} := \text{TimeCoeffs}_{\text{qtr},0} \cdot \text{LargeAreaCost}$

$\text{QtrCost}_{\text{qtr},1} := \text{TimeCoeffs}_{\text{qtr},1} \cdot \text{MediumLargeAreaCost}$

$\text{QtrCost}_{\text{qtr},2} := \text{TimeCoeffs}_{\text{qtr},2} \cdot \text{MediumSmallAreaCost}$

$\text{QtrCost}_{\text{qtr},3} := \text{TimeCoeffs}_{\text{qtr},3} \cdot \text{SmallAreaCost}$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$\text{QtrSum}_{\text{qtr}} := \sum_k \text{QtrCost}_{\text{qtr},k}$$

Let years be indexed by

$$yr = 0..4$$

$$AnnualCost_0 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 2.93 \cdot B$$

$$AnnualCost_1 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 6.12 \cdot B$$

$$AnnualCost_2 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 8 \cdot B$$

$$AnnualCost_3 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 6.13 \cdot B$$

$$AnnualCost_4 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 2.67 \cdot B$$

As a check,

$$SumOfCost := \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 25.84 \cdot B$$

$$GrandTotalCapital = 25.84 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' -- to be defined -- cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "ascldat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{ascldat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{cell}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 0$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$
Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 3

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

$$\text{SignalCostPerIntersect} = 40 \cdot K$$

$$\text{SensorCostPerMile} = 50 \cdot K$$

$$Fr_{old} = 0.5$$

$$\text{VMSCostPerMile} = 40 \cdot K$$

$$\text{BeaconCostPerMile} = 0 \cdot K$$

$$\text{RadioCostPerMile} = 15 \cdot K$$

$$\text{CommCostPerMile} = 150 \cdot K$$

$$\text{CompHdweCostPerModule} = 175 \cdot K$$

$$\text{SoftweInstanceCostPerMile} = 2 \cdot K$$

$$\text{StaffCostPerModule} = 400 \cdot K$$

$$\text{BuildingCostPerModule} = 200 \cdot K$$

$$\text{SoftweOrigCostPerModule} = 350 \cdot K$$

$$\text{OtherCostPerMile} = 0$$

$$\text{SoftweUpdateCostPerModule} = 15 \cdot K$$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

$$\text{ElementCost}_{(1,0)} = 0 \quad (\text{will add in as 10\% after calculation of capital cost})$$

$$\text{ElementCost}_{1,1} = \text{SensorCostPerMile} \cdot \text{StatusFactor}_i \cdot \text{GeoFactor}_i \cdot \text{TotM}_i \cdot K$$

$$\text{ElementCost}_{1,2} = \text{SignalCostPerIntersect} \cdot \left(\frac{(\text{Intersect}_i \cdot Fr_{old} + \text{FwyM}_i)}{\text{FwyM}_i} \right) \cdot K$$

$$\text{ElementCost}_{1,3} = \text{VMSCostPerMile} \cdot \text{FwyM}_i \cdot \text{GeoFactor}_i \cdot \text{StatusFactor}_i \cdot K$$

$$\text{ElementCost}_{1,4} = \text{BeaconCostPerMile} \cdot (\text{FwyM}_i + \text{MinArtM}_i) \cdot K$$

$$\text{ElementCost}_{1,5} = \text{RadioCostPerMile} \cdot \text{FwyM}_i \cdot K$$

$$\text{ElementCost}_{1,6} = \text{CommCostPerMile} \cdot \text{TotM}_i \cdot \text{GeoFactor}_i \cdot K$$

$$\text{ElementCost}_{1,7} = \text{CompHdweCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{1,8} = \text{SoftweInstanceCostPerMile} \cdot \text{TotM}_i \cdot K + (\text{SoftweOrigCostPerModule} \cdot \text{Modules}_i)$$

$$\text{ElementCost}_{1,9} = \text{StaffCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{1,10} = \text{BuildingCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{(1,11)} = \text{OtherCostPerMile} \cdot K$$

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} := \text{InstalledCost}_i \cdot 0.1$$

Considering engineering as 10% of capital cost

74

SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 3.82 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 1.91 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 1.52 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 1.34 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' -- to be defined -- cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} = \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 8.59 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area — for maintenance — and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots$$

$$+ 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,6}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,6}$$

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SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 276.58 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 143.61 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 114.82 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 102.98 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 0.64 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr := 0..19

and index the area sizes by k, where

k := 0..3 ('0' is largest)

Recall that

$K = 1$

$M = 1 \cdot 10^3 \cdot K$

$B = 1 \cdot 10^3 \cdot M$

LargeAreaCost = $3.82 \cdot B$

and

MediumLargeAreaCost = $1.91 \cdot B$

MediumSmallAreaCost = $1.52 \cdot B$

SmallAreaCost = $1.34 \cdot B$

Then

$QtrCost_{qtr,0} := TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} := TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} := TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} := TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr = 0..4$$

$$AnnualCost_0 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 0.97 \cdot B$$

$$AnnualCost_1 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 2.03 \cdot B$$

$$AnnualCost_2 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 2.66 \cdot B$$

$$AnnualCost_3 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 2.04 \cdot B$$

$$AnnualCost_4 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 0.89 \cdot B$$

As a check,

$$SumOfCost := \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 8.59 \cdot B$$

$$GrandTotalCapital = 8.59 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,
element 1 is sensor cost,
element 2 is signal cost,
element 3 is variable-message sign cost,
element 4 is beacon cost (which will be 0 in some architectures),
element 5 is radio cost (which will be 0 in some architectures),
element 6 is communication 'cabling' cost,
element 7 is computer hardware original cost,
element 8 is computer software original cost,
element 9 is staff cost,
element 10 is cost of providing building space, and
element 11 is 'other' -- to be defined -- cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$

Population, in thousands

$\text{Modules}_i := \text{cell}\left(\frac{\text{Pop}_i}{10^3}\right)$

Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$

Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$

Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2),5}$

Number of (augmented) arterial miles

$\text{Aug} := 1$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$

Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$

Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$

Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 3

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

SignalCostPerIntersect = $40 \cdot K$

SensorCostPerMile = $50 \cdot K$

Fr_{old} = 0.5

VMSCostPerMile = $40 \cdot K$

BeaconCostPerMile = $0 \cdot K$

RadioCostPerMile = $15 \cdot K$

CommCostPerMile = $150 \cdot K$

CompHdweCostPerModule = $175 \cdot K$

SoftweInstanceCostPerMile = $2 \cdot K$

StaffCostPerModule = $400 \cdot K$

BuildingCostPerModule = $200 \cdot K$

SoftweOrigCostPerModule = $350 \cdot K$

OtherCostPerMile = 0

SoftweUpdateCostPerModule = $15 \cdot K$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

ElementCost_(1,0) = 0 (will add in as 10% after calculation of capital cost)

ElementCost_{1,1} = SensorCostPerMile · StatusFactor_i · GeoFactor_i · TotM_i · K

ElementCost_{1,2} = SignalCostPerIntersect · $\left(\frac{\text{Intersect}_i \cdot \text{Fr}_{\text{old}} + \text{FwyM}_i}{\text{FwyM}_i} \right) \cdot K$

ElementCost_{1,3} = VMSCostPerMile · FwyM_i · GeoFactor_i · StatusFactor_i · K

ElementCost_{1,4} = BeaconCostPerMile · $\left[\left(\text{FwyM}_i + \text{MinArtM}_i \right) \cdot K \right]$

ElementCost_{1,5} = RadioCostPerMile · FwyM_i · K

ElementCost_{1,6} = CommCostPerMile · TotM_i · GeoFactor_i · K

ElementCost_{1,7} = CompHdweCostPerModule · Modules_i · K

ElementCost_{1,8} = SoftweInstanceCostPerMile · TotM_i · K + (SoftweOrigCostPerModule · Modules_i)

ElementCost_{1,9} = StaffCostPerModule · Modules_i · K

ElementCost_{1,10} = BuildingCostPerModule · Modules_i · K

ElementCost_(1,11) = OtherCostPerMile · K

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(1,0)} := \text{InstalledCost}_i \cdot 1$$

Considering engineering as 10% of capital cost

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SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 10.9 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 5.46 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 4.32 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 3.81 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

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For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' — to be defined — cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} := \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 24.48 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area – for maintenance – and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots$$

$$+ 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,e}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,e}$$

74

SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 710.35 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 367.75 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 289.3 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 258.57 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 1.63 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr = 0..19

and index the area sizes by k, where

k = 0..3 ('0' is largest)

Recall that $K = 1$ $M = 1 \cdot 10^3 \cdot K$ $B = 1 \cdot 10^3 \cdot M$

LargeAreaCost = $10.9 \cdot B$

and

MediumLargeAreaCost = $5.46 \cdot B$

MediumSmallAreaCost = $4.32 \cdot B$

SmallAreaCost = $3.81 \cdot B$

Then $QtrCost_{qtr,0} = TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} = TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} = TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} = TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr = 0..4$$

$$AnnualCost_0 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 2.78 \cdot B$$

$$AnnualCost_1 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 5.79 \cdot B$$

$$AnnualCost_2 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 7.57 \cdot B$$

$$AnnualCost_3 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 5.8 \cdot B$$

$$AnnualCost_4 = \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 2.53 \cdot B$$

As a check,

$$SumOfCost = \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 24.48 \cdot B$$

$$GrandTotalCapital = 24.48 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' -- to be defined -- cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{ceil}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 0$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intersect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$

Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 4

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

$$\text{SignalCostPerIntersect} := 40 \cdot K$$

$$\text{SensorCostPerMile} := 50 \cdot K$$

$$Fr_{old} = 0.5$$

$$\text{VMSCostPerMile} = 40 \cdot K$$

$$\text{BeaconCostPerMile} := 50 \cdot K$$

$$\text{RadioCostPerMile} := 15 \cdot K$$

$$\text{CommCostPerMile} := 150 \cdot K$$

$$\text{CompHdweCostPerModule} := 175 \cdot K$$

$$\text{SoftweInstanceCostPerMile} := 2 \cdot K$$

$$\text{StaffCostPerModule} := 400 \cdot K$$

$$\text{BuildingCostPerModule} := 200 \cdot K$$

$$\text{SoftweOrigCostPerModule} := 350 \cdot K$$

$$\text{OtherCostPerMile} := 0$$

$$\text{SoftweUpdateCostPerModule} := 15 \cdot K$$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

$$\text{ElementCost}_{(1,0)} := 0 \quad (\text{will add in as 10\% after calculation of capital cost})$$

$$\text{ElementCost}_{1,1} := \text{SensorCostPerMile} \cdot \text{StatusFactor}_i \cdot \text{GeoFactor}_i \cdot \text{TotMi}_i \cdot K$$

$$\text{ElementCost}_{1,2} := \text{SignalCostPerIntersect} \cdot \left(\frac{\text{Intersect}_i \cdot Fr_{old} + \text{FwyMi}_i}{\text{FwyMi}_i} \right) \cdot K$$

$$\text{ElementCost}_{1,3} := \text{VMSCostPerMile} \cdot \text{FwyMi}_i \cdot \text{GeoFactor}_i \cdot \text{StatusFactor}_i \cdot K$$

$$\text{ElementCost}_{1,4} := \text{BeaconCostPerMile} \cdot \left[\left(\text{FwyMi}_i + \text{MinArtMi}_i \right) \cdot K \right]$$

$$\text{ElementCost}_{1,5} := \text{RadioCostPerMile} \cdot \text{FwyMi}_i \cdot K$$

$$\text{ElementCost}_{1,6} := \text{CommCostPerMile} \cdot \text{TotMi}_i \cdot \text{GeoFactor}_i \cdot K$$

$$\text{ElementCost}_{1,7} := \text{CompHdweCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{1,8} := \text{SoftweInstanceCostPerMile} \cdot \text{TotMi}_i \cdot K + \left(\text{SoftweOrigCostPerModule} \cdot \text{Modules}_i \right)$$

$$\text{ElementCost}_{1,9} := \text{StaffCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{1,10} := \text{BuildingCostPerModule} \cdot \text{Modules}_i \cdot K$$

$$\text{ElementCost}_{(1,11)} := \text{OtherCostPerMile} \cdot K$$

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} := \text{InstalledCost}_i \cdot 1$$

Considering engineering as 10% of capital cost

74

SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 4.41 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 2.25 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 1.76 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 1.56 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

11

For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
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 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' — to be defined — cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} := \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 9.97 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area — for maintenance — and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot \left(\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots \right) \dots$$

$$+ 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,s}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,s}$$

74

SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 335.43 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 176.77 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 138.89 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 125.42 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 0.78 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr := 0..19

and index the area sizes by k, where

k := 0..3 ('0' is largest)

Recall that

K = 1

M = $1 \cdot 10^3 \cdot K$

B = $1 \cdot 10^3 \cdot M$

LargeAreaCost = $4.41 \cdot B$

and

MediumLargeAreaCost = $2.25 \cdot B$

MediumSmallAreaCost = $1.76 \cdot B$

SmallAreaCost = $1.56 \cdot B$

Then

$QtrCost_{qtr,0} := TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} := TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} := TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} := TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr := 0..4$$

$$AnnualCost_0 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr < 4)$$

$$AnnualCost_0 = 1.12 \cdot B$$

$$AnnualCost_1 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$AnnualCost_1 = 2.36 \cdot B$$

$$AnnualCost_2 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$AnnualCost_2 = 3.09 \cdot B$$

$$AnnualCost_3 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$AnnualCost_3 = 2.37 \cdot B$$

$$AnnualCost_4 := \sum_{qtr} QtrSum_{qtr} \cdot (qtr > 15)$$

$$AnnualCost_4 = 1.03 \cdot B$$

As a check,

$$SumOfCost := \sum_{yr} AnnualCost_{yr}$$

$$SumOfCost = 9.97 \cdot B$$

$$GrandTotalCapital = 9.97 \cdot B$$

APPENDIX

Cost Estimates for ATMS Implementation: Computational Procedures

We will begin by defining the individual elements of cost of implementing ATMS in the largest 75 metropolitan areas, the characteristics of the areas themselves, and the dependencies of the elements on size, miles, or some other characteristic.

Estimated cost for each area will then be computed by summing the element costs for that area. Estimated total cost of implementation will then be computed by summing the area costs.

Data about the individual areas will be stored and maintained external to this model and read into the computation when the model is executed. Some values are experts' estimates, and derived values are assumed explicitly in the model. In this report, all available metropolitan area data are utilized. The data will be stored outside the model.

INDEX DEFINITIONS

Let the metropolitan areas be indexed by 'i', where

$i = 0..74$ and the areas are those identified in the
1990 census (e.g., New York, the largest, is area 0),

and let the cost elements be indexed by 'j', where

$j = 0..11$

element 0 is planning and engineering cost,

element 1 is sensor cost,

element 2 is signal cost,

element 3 is variable-message sign cost,

element 4 is beacon cost (which will be 0 in some architectures),

element 5 is radio cost (which will be 0 in some architectures),

element 6 is communication 'cabling' cost,

element 7 is computer hardware original cost,

element 8 is computer software original cost,

element 9 is staff cost,

element 10 is cost of providing building space, and

element 11 is 'other' — to be defined — cost.

Costs are stated as per-mile or other appropriate unit costs, and then multiplied by the appropriate factor to calculate element cost for a particular area.

READ IN AREA CHARACTERISTIC DATA

Assume that some of the characteristics of the metropolitan areas are stored in the rows of an ASCII file (named "asciidat.prn"), ordered by size rank, with each row of the file containing the area's population, number of freeway miles, number of arterial miles, number of signalized intersections, and adjustment factors for geographic location and current status of advanced traffic management planning or implementation. We access the file with 'READ' statements. For programming convenience, we'll define a data matrix for temporary storage, read into it, and pick out the individual characteristic data for further use.

Index the characteristics by 'k', where

$k := 0..5$

Then $\text{data} := \text{READPRN}(\text{asciidat})$

$\text{Pop}_i := \text{data}_{i,0}$ Population, in thousands

$\text{Modules}_i := \text{cell}\left(\frac{\text{Pop}_i}{10^3}\right)$ Number of TMC modules

$\text{FwyMi}_i := \text{data}_{i,1}$ Number of freeway miles

$\text{MinArtMi}_i := \text{data}_{i,2}$ Number of arterial miles

$\text{AugArtMi}_i := \text{data}_{(i,2) \cdot 5}$ Number of (augmented) arterial miles

$\text{Aug} := 1$ 'Aug' lets us consider the two cases...

$\text{TotMi}_i := \text{if}(\text{Aug} > 0, \text{FwyMi}_i + \text{AugArtMi}_i, \text{FwyMi}_i + \text{MinArtMi}_i)$

$\text{Intrsect}_i := \text{if}(\text{Aug} > 0, \text{data}_{i,3} \cdot 5, \text{data}_{i,3})$

Number of intersections controlled

$\text{GeoFactor}_i := \text{data}_{i,4}$ Factor to adjust for differing construction costs by climate and differing intersection density

$\text{StatusFactor}_i := \text{data}_{i,5}$ Factor to adjust for planning and implementation already existing

DEFINE UNIT COSTS FOR ARCHITECTURE 4.

Costs will be given in K (thousands), M (millions), or B (billions)

where $K = 1$ $M = 1000 \cdot K$ and $B = 1000 \cdot M$

$$\text{SignalCostPerIntrsect} = 40 \cdot K$$

$$\text{SensorCostPerMile} = 50 \cdot K$$

$$Fr_{old} = 0.5$$

$$\text{VMSCostPerMile} = 40 \cdot K$$

$$\text{BeaconCostPerMile} = 50 \cdot K$$

$$\text{RadioCostPerMile} = 15 \cdot K$$

$$\text{CommCostPerMile} = 150 \cdot K$$

$$\text{CompHdweCostPerModule} = 175 \cdot K$$

$$\text{SoftweInstanceCostPerMile} = 2 \cdot K$$

$$\text{StaffCostPerModule} = 400 \cdot K$$

$$\text{BuildingCostPerModule} = 200 \cdot K$$

$$\text{SoftweOrigCostPerModule} = 350 \cdot K$$

$$\text{OtherCostPerMile} = 0$$

$$\text{SoftweUpdateCostPerModule} = 15 \cdot K$$

(will be added as needed)

CALCULATE COST ELEMENTS FOR EACH AREA

The elements of cost, as listed above, can then be calculated for each specific area.

$$\text{ElementCost}_{(1,0)} = 0 \quad (\text{will add in as 10\% after calculation of capital cost})$$

$$\text{ElementCost}_{1,1} = \text{SensorCostPerMile} \cdot \text{StatusFactor}_1 \cdot \text{GeoFactor}_1 \cdot \text{TotM}_1 \cdot K$$

$$\text{ElementCost}_{1,2} = \text{SignalCostPerIntrsect} \cdot \left(\frac{\text{Intrsect}_1 \cdot Fr_{old} + \text{FwyM}_1}{\text{FwyM}_1} \right) \cdot K$$

$$\text{ElementCost}_{1,3} = \text{VMSCostPerMile} \cdot \text{FwyM}_1 \cdot \text{GeoFactor}_1 \cdot \text{StatusFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,4} = \text{BeaconCostPerMile} \cdot \left[(\text{FwyM}_1 + \text{MinArtM}_1) \cdot K \right]$$

$$\text{ElementCost}_{1,5} = \text{RadioCostPerMile} \cdot \text{FwyM}_1 \cdot K$$

$$\text{ElementCost}_{1,6} = \text{CommCostPerMile} \cdot \text{TotM}_1 \cdot \text{GeoFactor}_1 \cdot K$$

$$\text{ElementCost}_{1,7} = \text{CompHdweCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,8} = \text{SoftweInstanceCostPerMile} \cdot \text{TotM}_1 \cdot K + (\text{SoftweOrigCostPerModule} \cdot \text{Modules}_1)$$

$$\text{ElementCost}_{1,9} = \text{StaffCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{1,10} = \text{BuildingCostPerModule} \cdot \text{Modules}_1 \cdot K$$

$$\text{ElementCost}_{(1,11)} = \text{OtherCostPerMile} \cdot K$$

SUM CAPITAL COSTS FOR THE INDIVIDUAL METROPOLITAN AREAS

With elements of cost and characteristics of the individual areas defined, total estimated cost for each area can be calculated by summing over the elements of cost.

$$\text{InstalledCost}_i := \sum_j \text{ElementCost}_{i,j} \cdot (j < 9)$$

$$\text{CapitalCost}_i := \text{InstalledCost}_i \cdot 1.1$$

$$\text{ElementCost}_{(i,0)} = \text{InstalledCost}_i \cdot 1$$

Considering engineering as 10% of capital cost

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SUM CAPITAL COSTS BY SIZE OF AREAS

To sum costs for the largest 9 metropolitan areas, (pop > 4M) we sum from 0 to 8;

$$\text{LargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i < 9)$$

$$\text{LargeAreaCost} = 11.49 \cdot B$$

Similarly,

$$\text{MediumLargeAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaCost} = 5.79 \cdot B$$

$$\text{MediumSmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaCost} = 4.55 \cdot B$$

$$\text{SmallAreaCost} := \sum_i \text{CapitalCost}_i \cdot (i > 40)$$

$$\text{SmallAreaCost} = 4.03 \cdot B$$

SUM CAPITAL COSTS BY ELEMENT OF COST

$$\text{ElementCapitalCost}_j = \sum_i \text{ElementCost}_{(i,j)}$$

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For reference, remember that

element 0 is planning and engineering cost
 element 1 is sensor cost,
 element 2 is signal cost,
 element 3 is variable-message sign cost,
 element 4 is beacon cost,
 element 5 is radio cost,
 element 6 is communication 'cabling' cost,
 element 7 is computer hardware original cost,
 element 8 is computer software original cost,
 element 9 is staff cost,
 element 10 is cost of providing building space, and
 element 11 is 'other' — to be defined — cost.

SUM CAPITAL COSTS FOR ALL METROPOLITAN AREAS

To estimate the grand total capital cost for all areas, we simply sum the estimated costs for every area.

$$\text{GrandTotalCapital} := \sum_i \text{CapitalCost}_i$$

With the stated assumptions, the grand total is

$$\text{GrandTotalCapital} = 25.86 \cdot B$$

SUM RECURRING COSTS FOR INDIVIDUAL METROPOLITAN AREAS

To estimate costs for operations and maintenance, we take 10% of the capital cost for an area – for maintenance – and add the projected other recurring costs (for example, salary and training).

$$\text{RecurringCost}_i := \text{Modules}_i \cdot (\text{BuildingCostPerModule} \cdot 0.1 + \text{StaffCostPerModule} \dots) \dots \\ + 0.1 \cdot \left(\frac{\text{CapitalCost}_i - \text{ElementCost}_{i,s}}{\dots} \right) + 0.03 \cdot \text{ElementCost}_{i,s}$$

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SUM RECURRING COSTS BY SIZE OF AREA

$$\text{LargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i < 9)$$

$$\text{LargeAreaRecurringCost} = 769.2 \cdot M$$

$$\text{MediumLargeAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 8) \cdot (i < 22)$$

$$\text{MediumLargeAreaRecurringCost} = 400.91 \cdot M$$

$$\text{MediumSmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 21) \cdot (i < 41)$$

$$\text{MediumSmallAreaRecurringCost} = 313.17 \cdot M$$

$$\text{SmallAreaRecurringCost} := \sum_i \text{RecurringCost}_i \cdot (i > 40)$$

$$\text{SmallAreaRecurringCost} = 281.01 \cdot M$$

$$\text{TotalRecurringCost} := \sum_i \text{RecurringCost}_i$$

$$\text{TotalRecurringCost} = 1.76 \cdot B$$

To estimate the distribution of ATMS implementation costs over the next five years, we begin by assuming spending profiles for projects. We assume that large projects take longer than small projects, but that the shapes of the spending curves are similar. We further assume that large areas are farther along in the ATMS process, and hence can begin sooner. For convenience, we store the profiles in a separate ASCII file called 'TIMEDIST.PRN', where each row of the file contains the fraction of total project cost that is spent during a particular 3-month interval and the 20 rows therefore represent spending profiles for five years. Again, we access the file with a 'READPRN' statement and store the data in a temporary array.

TimeCoeffs := READPRN(timedist prn)

Index the data by quarters, where

qtr := 0..19

and index the area sizes by k, where

k := 0..3 ('0' is largest)

Recall that

$K = 1$

$M = 1 \cdot 10^3 \cdot K$

$B = 1 \cdot 10^3 \cdot M$

LargeAreaCost = 11.49 · B

and

MediumLargeAreaCost = 5.79 · B

MediumSmallAreaCost = 4.55 · B

SmallAreaCost = 4.03 · B

Then $QtrCost_{qtr,0} = TimeCoeffs_{qtr,0} \cdot LargeAreaCost$

$QtrCost_{qtr,1} = TimeCoeffs_{qtr,1} \cdot MediumLargeAreaCost$

$QtrCost_{qtr,2} = TimeCoeffs_{qtr,2} \cdot MediumSmallAreaCost$

$QtrCost_{qtr,3} = TimeCoeffs_{qtr,3} \cdot SmallAreaCost$

For example,

To get total implementation cost by year, we sum over the area costs and then sum the quarters in groups of four.

$$QtrSum_{qtr} := \sum_k QtrCost_{qtr,k}$$

Let years be indexed by

$$yr := 0..4$$

$$\text{AnnualCost}_0 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr < 4)$$

$$\text{AnnualCost}_0 = 2.93 \cdot B$$

$$\text{AnnualCost}_1 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 3) \cdot (qtr < 8)$$

$$\text{AnnualCost}_1 = 6.12 \cdot B$$

$$\text{AnnualCost}_2 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 7) \cdot (qtr < 12)$$

$$\text{AnnualCost}_2 = 8 \cdot B$$

$$\text{AnnualCost}_3 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 11) \cdot (qtr < 16)$$

$$\text{AnnualCost}_3 = 6.13 \cdot B$$

$$\text{AnnualCost}_4 := \sum_{qtr} \text{QtrSum}_{qtr} \cdot (qtr > 15)$$

$$\text{AnnualCost}_4 = 2.68 \cdot B$$

As a check,

$$\text{SumOfCost} := \sum_{yr} \text{AnnualCost}_{yr}$$

$$\text{SumOfCost} = 25.86 \cdot B$$

$$\text{GrandTotalCapital} = 25.86 \cdot B$$

DATE

FILMED

7/26/94

END