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Chapter 4
System Architecture

Alternatives Considered

The system architecture provides a framework for the coordination of the various elements that comprise the intelligent transportation system (ITS). Three alternatives were considered in the process of selecting an architecture for the Kansas City area. Each architecture was evaluated for three scenarios representing various levels of geographic coverage and infrastructure investment, as shown in Figure 4-1.

The Level 1 System includes a limited number of corridors, namely the downtown loop, I-35 north to I-29, I-35 south to I-435, I-70 east to US 40 (east of I-435), I-435 from Bannister Road in Missouri to I-35 in Kansas, and US 71 from I-470 to the Blue Ridge Extension. This system provides coverage on approximately 48 miles of freeway. The Level 2 System includes all of the Level 1 System, as well as 34 additional miles. The Level 2 System extends to include I-670, I-70 west of downtown to I-635, I-70 from US 40 to I-470, I-635 between I-70 and I-35, US 69 between I-35 and I-435, I-29 in Clay County north of I-35, and I-435 from Bannister Road to Independence Avenue. The Level 2 System would be expected to provide benefits not only from the standpoint that it substantially increases the freeway coverage, but also from the standpoint that it provides additional redundancy by completing several loops. The Level 3 System includes full deployment on all interstates and major freeways in the metropolitan area (approximately 258 miles of roadway).

Level 1, 2 and 3 scenarios were evaluated so that the full impact of various characteristics, such as the number of traffic operations centers, control logic, and data processing, could be examined, particularly with respect to cost. For example, the cost associated with two traffic operations centers may be relatively insignificant when compared to the cost of the Level 3 System, however, this cost may be very significant when considered relative to the cost of the Level 1 System.

The analysis discussed in this chapter was designed to determine which architecture (A, B, or C) was most appropriate for the Kansas City intelligent transportation system. This analysis was not designed to determine the geographic extent of the system. The geographic extent of the system recommended for deployment is based on the benefit cost analysis discussed in Chapter 6. Because the utility factors specified for each alternative are considered valid only relative to the various architecture alternatives, and not relative to the geographic extent of the system, comparisons should be made only between alternatives (A, B and C) at the same "level".

CHARACTERISTICS

The three architecture alternatives are defined by seven characteristics, which are shown in Table 4-1 and discussed in the following text.

Table 4-1. Description of System Architecture Alternatives

Characteristic	Alternative A Centralized	Alternative B Decentralized	Alternative C Hybrid Recommended
Control Logic	Single server	Two servers with central information server	**Two servers with central information server**
Number of Traffic Operations Centers (TOCs)	1	2	**1**
Data Processing	Centralized	Decentralized	**Centralized**
Communications Network	Fiber - star/ring configuration	Fiber - star/ring configuration	**Fiber - star/ring configuration**
Emergency Management Coordination	Maintain existing 911 dispatch and move some emergency personnel into traffic operations center	Maintain existing 911 dispatch, traffic operations center will contact emergency responders directly	**Maintain existing 911 dispatch, traffic operations center will contact emergency responders directly**
Arterial Signal Control	Hybrid system (some arterials integrated into traffic operations center)	Stand-alone control (existing system)	**Hybrid system (some arterials integrated into traffic operations center)**
Public Transit	Hybrid system (incorporate some transit agencies into traffic operations center)	Maintain public transportation management functions outside of traffic operations center	**Maintain public transportation management functions outside of traffic operations center**

Control Logic - The first characteristic is control logic. The alternatives considered include single server control logic (Alternative A), in which all of the data processing for the entire metropolitan area is conducted through a single server, or a system with two servers, one for each state, with a central information server to exchange information between the servers and to provide information to outside sources, such as the media and traffic reporting agencies (Alternatives B and C).

Number of Traffic Operations Centers (TOCs)- The options considered with respect to traffic operations centers (TOCs) include either a single traffic operations center for the entire metropolitan area (Alternatives A and C), or separate traffic operations centers for each state (Alternative B). One advantage of the latter option is that it would allow each state to move forward independently, as funding permits. An advantage of a single traffic operations center is that it would facilitate coordination of activities on both sides of the state line. A single TOC might also present some economies of scale. Note that specification of a single TOC does not imply that there has to be single server control logic, and in fact, Alternative C specifies two servers housed in a single TOC, which would allow autonomy for each state while facilitating coordination between states.

Data Processing - Data processing alternatives include centralized (Alternatives A and C) and decentralized data processing (Alternative B). In centralized data processing, most of the data is processed at the central server. In decentralized data processing, more of the data processing is conducted in the field, and processed data is returned to the TOC. With decentralized data processing, some control decisions are automatically made in the field based on the results of the data processing. Decentralized data processing reduces the amount of data communicated to the TOC as well as the load on the central server(s). Decentralized control may imply increased reliability, because the system is less dependent on the central server. However, any increase in reliability due to increased redundancy with respect to data processing and control capabilities would be expected to result in an associated increase in cost. Furthermore, there may be increased maintenance requirements due to the fact that the equipment is not housed in a single location.

Communications Network - The communications network specified for all three alternatives is a dual ring fiber optics network in a star/ring configuration. Fiber optics was selected because it provides capacity adequate for most ITS applications and has been proven in applications in other urban areas. Fiber optic communications was also chosen because fiber has been installed in the right-of-way on all Missouri's interstates (and some freeways). This installation is the result of a private/public partnership. The Kansas Department of Transportation (KDOT) is pursuing a similar arrangement.

The star/ring configuration was chosen for a couple of reasons. One reason is because the star/ring configuration provides more redundancy than many other configurations. Information can always travel in the opposite direction in the event of a break in the line or an equipment failure. Another reason is because this configuration best suits the geometry of the freeways in Kansas City. There could ultimately be a number of rings and partial rings, including I-435, I-635 and I-470. The spokes, or legs of the star, include I-35, I-29 and I-70. Note that the system may initially include only selected facilities and would be expected to evolve, encompassing additional spokes and ring segments as is justified by volume and accident characteristics.

Emergency Management Coordination - All of the alternatives would maintain the existing 911 dispatch system.[1] The existing 911 dispatch system began operating in February 1983, and now encompasses the seven county region of Johnson, Leavenworth, and Wyandotte Counties in Kansas, and Cass, Clay, Jackson, and Platte Counties in Missouri. There are over 30 primary and secondary answer points in the region, which is served by four telephone companies. Southwestern Bell Telephone provides service to the majority of the area, with the remainder served by Sprint/United Telephone, which provides service to the rural portions of several counties, and by GTE and Mo-Kan Dial, which serve portions of Cass County. Sprint/United, GTE, and Mo-Kan Dial route calls from their central offices to the 911 tandem computer which is located in Southwestern Bell's Hedrick Office in Overland Park, Kansas. The calls are then routed to the appropriate answer point.

The variance between the alternatives with respect to Emergency Management Coordination is the degree to which and the way in which the TOC interfaces with the emergency responders. Under Alternative A, representative emergency personnel would be located in the TOC. This staff would serve as a liaison with emergency responders; for example, they may suggest the

[1] Discussion of the 911 system is based on information provided in the Draft 9-1-1 Policy Statement, Mid-America Regional Council, November 1993.

quantity and kind of emergency personnel and equipment needed based on the video provided by the closed circuit televisions operated by the TOC. Under Alternatives B and C, the TOC and the emergency management agencies function more autonomously. The TOC staff would contact the emergency responders directly, for example by telephone or radio, in the event of an emergency identified by the monitoring system. Under this alternative, it would also be possible for some 911 answer points to have video feed from the closed circuit televisions controlled by the TOC.

Arterial Signal Control - The management of signal systems is of particular importance on arterials that might be used for diversion of traffic from the freeway following an incident. One alternative is to allow local jurisdictions to maintain control of their arterial signal systems (Alternative B). Under this scenario, the TOC would notify the local jurisdiction when there is an incident that might result in increased traffic on local streets. The city could then modify the signal timings as they deem appropriate. Another alternative would be to control selected arterials from the TOC, while the remaining signals would continue to be controlled by local jurisdictions (Alternatives A and C). Traffic signals that might be controlled by the TOC include signals on major arterials identified as diversion routes, as well as signals under the jurisdiction of Missouri Highway and Transportation Department (MHTD).

Public Transportation - The management of public transportation includes dispatching transit vehicles and monitoring transit vehicle location, both through traditional radio communications, as well as through more advanced systems such as automatic vehicle location systems. The options considered for coordination between the TOC and public transportation include locating selected local transit systems in the TOC (Alternative A), or maintaining public transportation management activities outside the TOC (Alternatives B and C). Locating some transit management functions in the TOC is justified by the fact that monitoring activities allow public transit vehicles to serve as traffic probes, providing information to the TOC on traffic conditions and incidents. Furthermore, public transit can benefit from the information provided by the TOC, as buses can be re-routed to avoid congestion due to an incident. Keeping transit management outside the TOC is justified by the fact that relatively few buses use the freeways in Kansas City, which is the focus of the ITS system.

Evaluation Criteria

Evaluation of the three alternative architectures was conducted based on the utility-cost analysis using the seven evaluation criteria shown in Table 4-2 and discussed in the following text.

Cost - The evaluation with respect to cost includes consideration of capital costs, both the initial cost of equipment and software, as well as the cost for later enhancements to the system. The evaluation with respect to cost also must consider ongoing costs, namely the maintenance and operating costs of the system.

Reliability - The evaluation criteria reliability includes consideration of the reliability of the field equipment, communications equipment and data processing equipment, as well as the impacts

Table 4-2. System Architecture Evaluation Criteria

Criteria	Description
Cost	Initial cost for equipment and software
	Incremental cost for later enhancements
	Maintenance cost
	Operating cost
Reliability	Field equipment reliability
	Reliability of communications media
	Reliability of data processing equipment
	Reliability of TOC software/hardware
	Capability to monitor and control operations in the event of a break in communications capability
	Extent of loss in capability due to a single break in communications capability
Flexibility	Capability for equipment to operate independently or be controlled by the TOC
	Capability for one state to proceed independent of the other
Expandability	Extent to which system can be modified to provide additional capabilities at a later time (e.g. equipment)
	Ease with which the system can be expanded to encompass additional geographic areas
Staged Deployment	Ease of staged deployment with respect to geography and technology
Arterial Diversion	Ease with which an arterial diversion scheme could be implemented, for example, number of TOCs or entities that would need to be involved to change signal timing along an alternate route following an incident
Institutional Considerations	Whether architecture is compatible with existing institutional framework, or whether new institutional arrangements would be necessary (for example, coordination with KDOT, MHTD and emergency responders)

that result from an equipment failure. The impact of an equipment failure includes consideration of the expected failure rate, as well as well as the capability of the system to accommodate failure, which is based on the level of redundancy in the system.

Flexibility - The flexibility of the system refers both to the capability of system functions to be operated independently of the TOC, and for one state to proceed independently of the other.

Expandability - The expandability of the system includes the expandability with respect to the capability to include new technologies in the future, as well as the capability to expand geographically to encompass additional corridors or extensions of existing corridors.

Staged Deployment - Staged deployment refers to the ease with which the proposed architecture can be deployed in discrete but operable segments over a period of time. The project may be segmented with respect to either geography, with certain corridors operational prior to others, or with respect to technology, with more advanced equipment being implemented as funding is available or as is justified by changes in operating conditions.

Arterial Diversion - The ease with which an arterial diversion scheme can be implemented will impact the effectiveness of such a response, as well as the propensity for an arterial diversion scheme to be implemented. The capability for arterial diversion will depend on the operating agreements with local jurisdictions, as well as the sophistication of the signal control equipment on the affected arterials.

Institutional Considerations - The feasibility of each alternative with respect to institutional considerations must be evaluated. A system that is technically satisfactory will be of no benefit if it cannot be implemented due to institutional obstacles.

Analysis Procedure

A utility-cost analysis procedure was used to evaluate the three system architectures proposed by the study team for the Kansas City area[1]. This technique is commonly used because the comparative factors are easily computed. The utility-cost factor (*U-C*) was computed for each architecture alternative as the sum of the system utilities (defined by the evaluation criteria) divided by the sum of the system costs. A higher utility cost factor represents a preferable system, because the benefits are higher in proportion to the costs. Note that in this analysis, the cost of the system was considered as a benefit or utility (with lower cost resulting in a higher utility) in the numerator as well as the denominator.

UTILITIES

The sum of the utilities is the weighted combination of the individual evaluation criteria.

(Eqn 4-1)

$$U = k_1u_1 + k_2u_2 + k_3u_3 + k_4u_4 + k_5u_5 + k_6u_6 + k_7u_7$$

where:
- U = Sum of Utilities
- u_1 = Utility due to Cost
- k_1 = Weighting Factor for Cost
- u_2 = Utility due to Reliability of System
- k_2 = Weighting Factor for Reliability
- u_3 = Utility due to Flexibility
- k_3 = Weighting Factor for Flexibility
- u_4 = Utility due to Expandability
- k_4 = Weighting Factor for Expandability
- u_5 = Utility due to Capability for Staged Deployment
- k_5 = Weighting Factor for Staged Deployment

[1] Discussion of utility-cost analysis is based on methodology described in "Computerized Signal Systems", an FHWA student workbook, June 1979.

u_6 = Utility due to Capability for Arterial Diversion
k_6 = Weighting factor for Arterial Diversion
u_7 = Utility due to Congruence with Institutional Considerations
k_7 = Weighting Factor for Institutional Considerations

The values for u_1 through u_7 were determined by the study team, and are shown in Table 4-3. Values for u_i range from 0 to 10, with 10 indicative of the highest utility. In Table 4-3, the values in bold indicate the utility factors for each criteria, values not in bold indicate utility factors for each component of the criteria. The values for k_1 through k_7 were determined based on input provided by the Steering Committee regarding the relative importance of each evaluation factor, as shown in Table 4-4. The average values excluding the high and low responses were used for the weighting factor, however examination of the other values calculated demonstrates that there was little variance between the mean, median, and mode. Note that the sum of k_1 through k_7 is equal to 100 percent. Additional information on the determination of the utility and weighting factors is provided in Appendix A.

COSTS

For evaluation purposes, the sum of the costs is calculated based on an equivalent annual value of the initial cost for equipment and software, plus the annual maintenance and operating costs:

(Eqn 4-2)

$$C = C_{CAPITAL} * I_{C-R} + C_{O-M}$$

where: C = Sum of Costs
$C_{CAPITAL}$ = Initial Capital Cost
C_{O-M} = Annual Operating and Maintenance Cost
I_{C-R} = Capital Recovery Factor to Convert Capital Cost to Equivalent Annual Payments (over a 15 year period at 6% interest)

Cost estimates for all alternatives are shown in Table 4-5. These values were used to calculate the utility for each alternative, and are also used in the denominator of the utility-cost factor.

UTILITY-COST FACTOR

Based on the values for the utility and weighting factors for each criteria (shown in Tables 4-3 and 4-4), as well as the costs shown in Table 4-5, the utility-cost factor for each alternative was calculated and is shown in Table 4-6. Note that the utility-cost factor for Alternative C is highest for each level of system deployment. This indicates that Alternative C is the most cost effective alternative. With respect to the utility associated with each alternative, Alternative B provides the highest expected benefit. This is offset, however, by the higher associated costs. Also note that as the system expands, the difference between the alternatives becomes less significant.

Table 4-3. Utility for Each Criteria by Architecture Alternative

	Utility	Level 1[1]			Level 2			Level 3		
		A	B	C	A	B	C	A	B	C
u_1	**Cost**	**7.4**	**7.2**	**7.4**	**6.1**	**5.9**	**6.0**	**0.5**	**0**	**0.5**
	Capital cost	7.3	7.2	7.3	6.0	5.8	6.0	0.5	0	0.5
	Maintenance and operating cost	7.7	7.1	7.7	6.2	6.0	6.2	0.5	0	0.5
u_2	**Reliability**	**4.2**	**5.8**	**6.2**	**4.8**	**5.8**	**6.4**	**5.4**	**5.8**	**6.6**
	Field equipment reliability	5	5	5	5	5	5	5	5	5
	Reliability of communications media	5	5	5	5	5	5	5	5	5
	Reliability of data processing equipment	5	4	7	5	4	7	5	4	7
	Capability to monitor and control operations in the event of a break in communications capability	3	8	7	4.5	8	7.5	6	8	8
	Extent of loss in capability due to single break in communications capability	3	7	7	4.5	7	7.5	6	7	8
u_3	**Flexibility**	**3.5**	**8**	**7**	**3.5**	**8**	**7**	**3.5**	**8**	**7**
	Capability for equipment to operate independently or be controlled by the TOC	3	7	6	3	7	6	3	7	6
	Capability for one state to proceed independent of the other	4	9	8	4	9	8	4	9	8
u_4	**Expandability**	**5**	**6**	**5**	**5**	**6**	**5**	**5**	**6**	**5**
	Extent to which system can be modified to provide additional capabilities at a later time	5	7	5	5	7	5	5	7	5
	Ease with which system can be modified to encompass additional geographic areas	5	5	5	5	5	5	5	5	5
u_5	**Staged Deployment**	**4**	**5**	**4**	**4**	**5**	**4**	**4**	**5**	**4**
u_6	**Arterial Diversion**	**8**	**4**	**8**	**8**	**4**	**8**	**8**	**4**	**8**
u_7	**Institutional Considerations**	**3**	**7**	**6**	**3**	**7**	**6**	**3**	**7**	**6**

[1] Level 1 System is 48 miles, Level 2 System is 82 miles, Level 3 System is 258 miles. Architecture Alternatives A, B and C are defined in Table 4-1.

Table 4-4. Steering Committee Recommendations for Weighting of Evaluation Criteria

Criteria		Mean[1]		Median	Mode	Value Used
		M_1	M_2			
k_1	Cost	19	19	20	20	19
k_2	Reliability	19	18	15	15	18
k_3	Flexibility	14	14	15	15	14
k_4	Expandability	16	16	15	15	16
k_5	Staged Deployment	13	14	15	10	14
k_6	Arterial Diversion	7	7	5	10	7
k_7	Institutional Considerations	12	12	10	10	12
Total		100	100	95	95	100

[1] M_1 is the mean value of all responses, M_2 is the mean value of all responses excluding the highest and lowest responses.

Recommended Architecture

The architecture recommended for deployment in the Kansas City area is Alternative C. This alternative includes two central servers with a central information server. This control logic will provide autonomy for the two states, yet will facilitate coordination and provide redundancy. Coordination will also be enhanced by specification of a single traffic operations center (TOC). With respect to data processing, the recommended alternative utilizes centralized data processing, which is the standard and proven system used in most applications across the country. The communications network is a dual ring fiber optics backbone in a star/ring configuration, which will have adequate capacity for all anticipated components. Emergency management coordination will be based on the existing 911 dispatch system. TOC operators will contact emergency responders directly using the 911 system. Follow up coordination may be via either telephone or radio. The recommended architecture takes a hybrid approach to arterial signal control. Some arterial signal systems will be controlled from the TOC, while others will be controlled outside the TOC, for example by cities. The TOC should work closely with cities that will maintain signal control, pre-planning appropriate timing plans and notifying city personnel in the event of an incident. The final characteristic identified by the architecture is coordination with public transit. Public transit functions will be maintained outside the TOC, although this does not preclude coordination of activities, particularly for the dissemination of information.

The recommended architecture includes some of the best features of both the completely centralized and decentralized systems. This architecture is compatible with the large number of local agencies, because it takes a hybrid approach to characteristics such as signal control. At the same time, specification of a single TOC will facilitate coordination and communication between the states, resulting in a seamless system for the entire metropolitan area.

Table 4-5. Estimated Cost for Each Alternative Architecture ($M)[1]

Item		Level 1[2]			Level 2			Level 3		
		A	B	C	A	B	C	A	B	C
$C_{CAPITAL}$	**Capital Cost**	**28.9**	**29.5**	**29.1**	**43.0**	**44.5**	**43.3**	**101**	**107**	**101**
	Closed circuit television (CCTV) cameras	2.88	2.88	2.88	4.92	4.92	4.92	15.5	15.5	15.5
	Detection	0.96	0.96	0.96	1.64	1.64	1.64	5.16	5.16	5.16
	Variable message signs	4.2	4.2	4.2	5.40	5.40	5.40	9.48	9.48	9.48
	Highway advisory radio	0.17	0.17	0.17	0.22	0.22	0.22	0.43	0.43	0.43
	Power, communications and conduit to equipment	12.1	12.1	12.1	18.8	18.8	18.8	44.6	44.6	44.6
	Field data processing equipment	0.96	1.92	0.96	1.64	3.28	1.64	5.16	10.3	5.16
	TOC	1.32	1.32	1.10	1.32	1.32	1.10	1.32	1.32	1.10
	Central hardware	0.81	0.60	0.96	0.92	0.71	1.07	1.51	1.30	1.66
	Software and systems integration	0.75	0.50	1.00	1.00	0.75	1.25	1.25	1.00	1.50
	Contingency and construction	4.82	4.92	4.86	7.17	7.41	7.21	16.9	17.8	16.9
$C_{O\text{-}M}$	**Annual Operating and Maintenance Cost**	**1.67**	**2.11**	**1.68**	**2.75**	**2.87**	**2.76**	**6.91**	**7.26**	**6.92**
	TOC personnel	0.35	0.70	0.35	0.70	0.70	07.0	1.75	1.75	1.75
	Maintenance personnel	0.25	0.30	0.25	0.40	0.45	0.40	1.10	1.20	1.10
	Replacement and spare parts and equipment	1.10	1.14	1.11	1.68	1.75	1.68	4.09	4.34	4.10
$I_{C\text{-}R}$	**Capital Recovery Factor[3]**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
C	**Sum of Costs per Year**	**4.68**	**5.18**	**4.71**	**7.21**	**7.48**	**7.24**	**17.4**	**18.3**	**17.4**

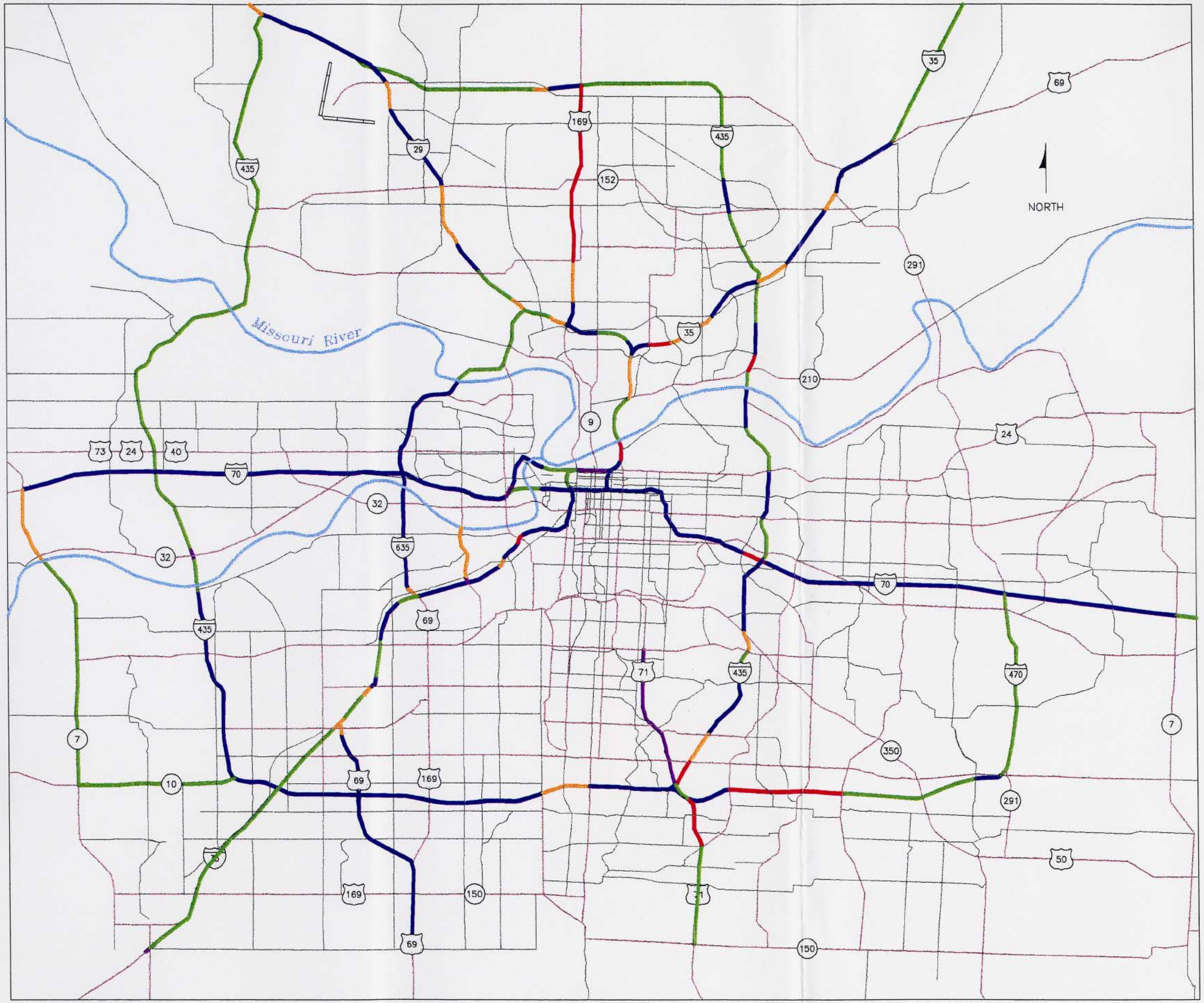
[1] All values are in millions of dollars except for the capital recovery factor.
[2] Level 1 System is 48 miles, Level 2 System is 82 miles, Level 3 System is 258 miles. Architecture Alternatives A, B and C are defined in Table 4-1.
[3] Based on 15 years with an interest rate of 6 percent.

Table 4-6. Calculation of Utility-Cost Factor for Each Architecture Alternative

	Level 1[1]			Level 2			Level 3		
	A	B	C	A	B	C	A	B	C
u_1	7.4	7.2	7.4	6.1	5.9	6.0	0.5	0	0.5
k_1	19	19	19	19	19	19	19	19	19
u_2	4.2	5.8	6.2	4.8	5.8	6.4	5.4	5.8	6.6
k_2	18	18	18	18	18	18	18	18	18
u_3	3.5	8	7	3.5	8	7	3.5	8	7
k_3	14	14	14	14	14	14	14	14	14
u_4	5	6	5	5	6	5	5	6	5
k_4	16	16	16	16	16	16	16	16	16
u_5	4	5	4	4	5	4	4	5	4
k_5	14	14	14	14	14	14	14	14	14
u_6	8	4	8	8	4	8	8	4	8
k_6	7	7	7	7	7	7	7	7	7
u_7	3	7	6	3	7	6	3	7	6
k_7	12	12	12	12	12	12	12	12	12
U	493	631	615	479	607	593	384	494	490
C[2]	4.68	5.18	4.71	7.21	7.48	7.24	17.4	18.3	17.4
U-C[3]	105	122	130	66	81	82	22	27	28

[1] Level 1 System is 48 miles, Level 2 System is 82 miles, Level 3 System is 258 miles. Architecture Alternatives A, B and C are defined in Table 4-1.
[2] Annual cost in millions of dollars.
[3] Utility cost factor.

ITS Early Deployment Study
Strategic Deployment Plan



Legend - Accidents per million vehicle miles traveled (1989 - 1994)

- Less than 1
- 1 to 2
- 2 to 3
- 3 to 4
- Greater than 4

FIGURE 2-9
Accident Rates
on Major Freeway Facilities

Source: Kansas – KDOT Accident Rate Data and High Frequency Accident Sections, January 1989 through December 1993.
Missouri – Rates calculated based on MHTD Accident Master Database and ADT, 1993 and 1994.