

# OPERATION GREEN LIGHT

## FINAL REPORT

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# Table of Contents

<b>1.0</b>	<b>Project Background .....</b>	<b>1</b>
1.1	Introduction .....	1
<b>2.0</b>	<b>Regional Signal Management Strategies .....</b>	<b>2</b>
2.1	Introduction .....	2
2.2	Houston TranStar .....	3
2.3	Las Vegas Area Computer Traffic System .....	7
2.4	Denver Regional Traffic Signal Improvement Program .....	11
2.5	Conclusions .....	13
<b>3.0</b>	<b>Signal System Inventory.....</b>	<b>14</b>
3.1	Introduction .....	14
3.2	Geographic Information System (GIS) .....	14
3.3	Data Collection.....	15
3.4	GIS Database.....	16
3.5	GIS Spatial Referencing.....	17
3.6	Results .....	17
<b>4.0</b>	<b>System Objectives .....</b>	<b>23</b>
4.1	Introduction .....	23
4.2	System Objectives .....	23
4.3	Constant-Sum Paired Comparison (CSPC).....	24
4.4	Establishing MARC System Priorities.....	25
4.5	CSPC Exercise Results.....	25



<b>5.0</b>	<b>System Elements .....</b>	<b>27</b>
5.1	Introduction .....	27
5.2	Signal Monitoring and Data Exchange Features .....	27
5.3	Detection Features .....	28
5.4	Security Features .....	29
5.5	Maintenance & Operations Features .....	30
5.6	Logical Linkages .....	31
5.7	Measures of Effectiveness Features .....	33
5.8	Video Monitoring (CCTV) Features .....	34
5.9	Communications System .....	36
5.10	Video Detection Features .....	43
5.11	Preemption & Priority Features .....	44
5.12	ITS Features .....	44
5.13	Flash Operation Features .....	46
5.14	High Water Event Features .....	46
5.15	System Elements Summary .....	46
<b>6.0</b>	<b>Signal System Areas.....</b>	<b>52</b>
6.1	Introduction .....	52
6.2	Coupling Index .....	52
6.3	Coupling Analysis Procedure .....	53
6.4	Control Group Determination .....	54
<b>7.0</b>	<b>Implementation Plan .....</b>	<b>58</b>
7.1	Introduction .....	58
7.2	Candidate Corridor Selection .....	58
7.3	Prioritization of Corridors .....	59
7.4	Field Hardware Implementation Costs .....	64
7.5	System Implementation Costs .....	72
7.6	Recommended Implementation Method .....	72
7.7	Operating & Maintenance Costs .....	74



<b>8.0</b>	<b>Air Quality Implications .....</b>	<b>76</b>
8.1	Introduction .....	76
8.2	The CMAQ Program .....	76
8.3	Operation Green Light Program (Phase I) .....	78
8.4	Travel Time Study .....	78
8.5	Reduction in Emissions .....	81
8.6	Results .....	84

## Appendices

- A. **MARC Corridors Listing**
- B. **Additional Non-MARC Study Corridors**
- C. **Regional Signal Management Strategies**
  - **Web Research Sites**
  - **Las Vegas Model**
- D. **Signal Inventory Data**
- E. **CSPC Results**
- F. **System Types & Summary**
- G. **Operations & Maintenance Costs**
- H. **Air Quality Data**

## List of Figures

1.	Signal Controller Age.....	20
2.	Signal Controller Type .....	21
3.	Signal Maintenance Data .....	22
4.	CCTV Plan .....	35
5.	Phase 1 Communications Plan .....	39
6.	Phase 2 Communications Plan .....	40
7.	Buildout Communications Plan .....	41
8.	Peak Hour Control Zones.....	56
9.	Off-Peak Control Zones .....	57
10.	Priority Corridors (South Area).....	61
11.	Priority Corridors (North Area).....	62
12.	Priority Corridors (East Area).....	63
13.	Travel Time Corridors.....	79

## List of Tables

1.	Infrastructure Requirements – Priority Corridors .....	67
2.	Infrastructure Requirements – Remaining Study Signals .....	68
3.	Cost Estimates – Controllers, Cabinets & Communications Priority Corridors & Remaining Study (Not Including Cost of Replacing Unknown Controller Types) .....	70
4.	Cost Estimates – Controllers, Cabinets & Communications Priority Corridors & Remaining Study (Including Cost of Replacing Unknown Controller Types).....	71
5.	Cost Estimate by Phase – Priority Corridors & Remaining Study Signals.....	73
6.	Annual Operations & Maintenance Cost .....	75
7.	TEA-21 CMAQ Apportionment Factors.....	77
8.	Travel Time Corridor Data.....	80
9.	Traffic Signal Improvements .....	83
10.	Reduction in Emissions at Full System Implementation .....	84
11.	Reduction in Emissions After Implementation of Phase I .....	84



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## Executive Summary

In March of 1998, the City of Kansas City, Missouri issued a solicitation for proposals from professional Consulting Engineers to develop a strategy to define and analyze alternative approaches to meeting the existing and future traffic signal needs in the city, with an aim towards providing optimum traffic movements and progressive flow patterns in the city. After several other local agencies requested consideration of participation in the process, the project was reformulated to take on a regional flavor, headed by the Mid-America Regional Council (MARC). The basis of this regional project was to focus on a number of corridors with regional significance from a traffic movement standpoint. This project was given Notice to Proceed in March of 1999, and in late 1999, the project was given the name Operation Green Light.

The project format was based on a series of monthly workshops where the consulting team, lead by BRW, Inc. of Phoenix, Arizona, conducted discussions on certain monthly topics, and then interacted with the Technical Advisory Committee for input and further discussion. The results on this study are intended to represent the majority viewpoint of the Technical Advisory Committee (TAC).

During the initial phases of the project, a Steering Committee, consisting of upper management participants of each local agency, was formed to undertake the task of determining the administrative and intergovernmental aspects of regional signal operations. The Steering Committee chose to pursue formation of a regional traffic signal operations authority to conduct day-to-day management and operation of the regional signal system.

During the conduct of this regional study, the consultants gathered information on existing signal control systems and communications infrastructure at over 1,400 traffic signals in the Kansas City region and developed a geographic information system (GIS) based inventory map which was provided to each agency.

During the course of the monthly project workshops, agency participants were briefed on a variety of technical issues regarding various operational strategies, necessary

hardware to support such strategies and a wide range of communications alternatives and approaches. Early on in the process, one workshop focused on establishing system goals and objectives, which served as the guidelines for selection of system components and features.

Subsequent workshops identified system elements, the parts and pieces that make up the physical portion, identified areas where signal control by a regional system would likely be beneficial, and developed an implementation plan to carry the concept to reality.

The approach selected with the Technical Advisory Committee was to implement a temporary radio communications system in areas where no existing traffic signal communications was in place and replace controller units with a uniform type capable of communication to other such system controllers to exchange data and coordinate the signals.

Eventually, the radio system would be phased out and replaced with a fiber optic backbone, linked to the new Scout freeway management system. That system would be capable of supporting the transmission of video and data from over 250 proposed CCTV sites, anticipated to be developed at a cost of approximately \$10 million.

Costs of the multi-phase project are shown on Table 5 on the next page, taken from Chapter 7 of this document. Estimated costs range from approximately \$5.7 million for the first phase, with a Buildout total cost of over \$30 million, plus an additional \$26 million for the regional fiber optic communications system.

Guidance on planning of the operations and maintenance costs necessary to continue successful operations once the system is implemented are provided.

An evaluation of the expected benefits of a regional traffic signal management system were modeled to determine the impact on air quality, as a result of improved traffic signal operations. The study concluded that the commutative effects of improved traffic flow will result in a reduction in hydrocarbons of 9% and a reduction in carbon monoxide of 14%.



**Table 5. Cost Estimate by Phase - Priority Corridors & Remaining Study Signals**

PHASE	Description	Total Number of Intersections	Design Cost	Central Hardware & Software	Controller & Cabinet (Installed)*	Radio Cost (Installed)	Signal Timing	System Management	Contingencies	Total Cost
I	Original Corridors	316	\$600,000	\$1,500,000	\$1,712,500	\$747,000	\$300,000	\$300,000	\$515,950	\$5,675,450
	Missouri Portion	178		\$1,110,000	\$1,287,500	\$525,000	\$168,000			\$3,090,500
	Kansas Portion Shared	138	\$600,000	\$390,000	\$425,000	\$222,000	\$132,000	\$300,000	\$515,950	\$1,415,950
IIA	Additional Corridors	117	\$100,000	\$100,000	\$1,150,000	\$267,000	\$100,000	\$50,000	\$176,700	\$1,943,700
	Missouri Portion	90		\$83,000	\$962,500	\$219,000	\$77,000			\$1,341,500
	Kansas Portion Shared	27	\$100,000	\$17,000	\$187,500	\$48,000	\$23,000	\$50,000	\$176,700	\$326,700
IIB	1 <sup>st</sup> Priority Interchange Ramps	94	\$100,000	\$100,000	\$675,000	\$267,000	\$100,000	\$50,000	\$129,200	\$1,421,200
	Missouri Portion	62		\$94,000	\$675,000	\$213,000	\$66,000			\$1,048,000
	Kansas Portion Shared	32	\$100,000	\$6,000	\$0	\$54,000	\$34,000	\$50,000	\$129,200	\$279,200
IIC	2 <sup>nd</sup> Priority Interchange Ramps	56	\$50,000	\$50,000	\$225,000	\$129,000	\$50,000	\$25,000	\$52,900	\$581,900
	Missouri Portion	36		\$41,000	\$187,500	\$102,000	\$32,000			\$362,500
	Kansas Portion Shared	20	\$50,000	\$9,000	\$37,500	\$27,000	\$18,000	\$25,000	\$52,900	\$127,900
III	Regional TOC		\$500,000	\$5,000,000				\$100,000	\$500,000	\$6,100,000
IV	Communications System		\$2,250,000	\$22,500,000				\$750,000	\$750,000	\$26,250,000
V	Remaining Study Signals on MARC Corridors	497	\$500,000	\$500,000	\$3,887,500	\$1,176,000	\$500,000	\$250,000	\$681,350	\$7,494,850
	Missouri Portion	318		\$345,000	\$2,625,000	\$879,000	\$320,000			\$4,169,000
	Kansas Portion Shared	179	\$500,000	\$155,000	\$1,262,500	\$297,000	\$180,000	\$250,000	\$681,350	\$1,431,350
VI	Remaining Study Signals not on MARC Corridors	420	\$400,000	\$400,000	\$4,037,500	\$999,000	\$400,000	\$200,000	\$643,650	\$7,080,150
	Missouri Portion	319		\$288,000	\$2,887,500	\$753,000	\$304,000			\$4,232,500
	Kansas Portion Shared	101	\$400,000	\$112,000	\$1,150,000	\$246,000	\$96,000	\$200,000	\$643,650	\$1,243,650

\* Includes new 2070 controller and cabinet at all locations with other than type 170 controller.

# 1.0 Project Background

## 1.1 INTRODUCTION

In March of 1998, the City of Kansas City, Missouri issued a solicitation for proposals from professional Consulting Engineers to develop a strategy to define and analyze alternative approaches to meeting the existing and future traffic signal needs in the city, with an aim towards providing optimum traffic movements and progressive flow patterns in the city.

In June of 1998, the consulting team of BRW, Inc. and Lee Engineering was selected and contract negotiations were initiated. However, as negotiations proceeded, the city was approached by several other agencies with signals in the area, and requests were made to include additional signals in the study.

The eventual outcome of these requests was the reformulation of the project to take on a regional flavor, headed by the Mid-America Regional Council (MARC). The basis of the project was to focus on a number of corridors with regional significance, from a traffic movement standpoint. These corridors are referred to herein as "the MARC corridors", and are listed specifically in Appendix A at the back of this report. Additional corridors, not officially part of the MARC corridors, but included in this study, were added at the expense of the participating requesting agencies and can be found listed in Appendix B.

This project was officially given Notice to Proceed in March of 1999, with an anticipated completion date of December 31, 2000. In late 1999, the project was named Operation Green Light.

The project format was based on a series of monthly workshops where the consulting team presented technical information and conducted discussions on certain monthly topics, and then interacted with the Technical Advisory Committee (TAC) for input and further discussion. The results on this study are intended to represent the majority viewpoint of the TAC, and it must be recognized that with such a large group, not all participants agreed wholly with all conclusions or results.

In a parallel process, a Steering Committee was formed and undertook the task of determining the administrative and intergovernmental aspects of regional signal operations, assuming one central system was intended for the entire region. The basis for those actions was laid out by the consulting team in the work for Task 1, Regional Signal Management Strategies, discussed further in the next section.

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## 2.0 Regional Signal Management Strategies

### 2.1 INTRODUCTION

The first workshop conducted for this project was a presentation of research on a variety of regional concepts of traffic signal management currently in operation around the United States to determine if any of them appeared to be a model applicable for use in the MARC region.

The task research consisted of the posting of information requests on the Institute of Transportation Engineers (ITE) listserv, telephone interviews with managers of traffic control systems where a regional timing was in effect, telephone interviews with regional transportation administrators, and web searches of the USDOT Electronic Document Library, and other transportation libraries. A complete list of web sites searched is documented in Appendix C.

The ITE listserv search produced surprisingly limited results identifying only three locations that responded to the question:

*Q: Are common signal timings used across political boundaries in your region?*

There was an initial response from thirteen jurisdictions asking to expand on the question, which was the intent of the original question. After discussion with the responders, the result was, as stated previously three jurisdictions. In addition to the ITE listserv, contact was made with members of ITS America=s Advanced Transportation Management System (ATMS) committee. The members contacted were Ed Rowe, former Transportation Director of Los Angeles, and Leslie Jacobson - Assistant Regional Administrator for Washington State Department of Transportation (WSDOT). Both committee members are recognized leaders in the development and deployment of Integrated Traffic Management Systems, and ITS in general.

In this report, four regional strategies, currently in place, were identified for review. They include Houston Metro, metropolitan Las Vegas, metropolitan Denver, and Santa Clara County in the Northern California Bay Area. All locations have implemented a functional form of regional traffic signal management. Interviews were conducted with the System Manager and with members of the individual agencies comprising the members of the Regional Structure. The interview topics, divided into two general categories – Political and Technical – covered, but are not limited to, the following issues:

***Political Issues***

- Organization Structure
- Jurisdictional Responsibilities
- Scope of Authority
- Political Control
- Funding

***Technical Issues***

- Maintenance Responsibilities
- Timing and Optimization
- Management Responsibilities
- Priority Setting

## **2.2 HOUSTON TRANSTAR**

### **Political Issues**

***Organization Structure***

Houston TranStar is comprised of representatives from the following Agencies:

- Houston Metro – the regional transit agency. In 1993 Metro underwent a reorganization which provided the agency with increased responsibilities, including traffic management;
- The Texas Department of Transportation (TxDOT);
- The City of Houston; and,
- Harris County.

The political structure is very complex and beyond the scope of this report to detail. However the makeup of Houston TranStar, is by comparison, relatively simple and is responsible for regional traffic signal timing, the focus of this task.

### ***Location***

TranStar is located in a 52,000 sq.ft. Transportation Management Center specially constructed to accommodate the many high technology components and integrated multi agency personnel. The Center is estimated to cost \$13.5 million, which includes design, construction and systems integration. The TranStar building includes a central control operations room, communications room, telephone switch room, briefing and operations room for special events and emergency conditions and three floors of offices for staff of the participating agencies. The building also contains viewing areas where the public and news media can learn more about the Center's operation, and monitor information during special and emergency events.

### ***Sections***

TranStar Division of Metro provides a coordinated regional effort between agencies to promote mobility in the metropolitan Houston area. The division is comprised of three sections that are:

- Incident & Emergency Management;
- Dispatch; and,
- Traffic Management Systems.

The Traffic Management Systems section is responsible for the programs and projects associated with Traffic Signals and ITS being implemented in the Houston region.

### ***Cost Sharing***

The Executive for Houston TranStar reports to an Executive Committee comprised of a representative from each of the Agencies. Each Agency contributes to the annual operating budget of the Center on a prorated basis relative to their occupancy and utilization of building components. While the cost pricing formulas are complex there seems to be no dissent to the agreement and all persons contacted agreed with the financial structure.

### ***Jurisdiction Responsibilities***

Currently each agency comprising TranStar, while co-located in the operations center, presides over the responsibilities of their own signal system thereby retaining local autonomy. Decisions determining timing parameters affecting more than one jurisdiction are made following discussion and then implemented by the jurisdiction owning the intersection. This method allows each jurisdiction to retain their own liabilities without transferring responsibility to adjoining agencies.

### ***Scope of Authority***

TranStar is responsible for the planning, design, operations and maintenance of transportation operations and emergency management operations within the Greater Houston Area. The service area encompasses 5,436 square miles with a population of 4.0 million.

TranStar is responsible for the management of a variety of freeway and arterial street systems including the coordination of Intelligent Transportation Systems (ITS) programs, Emergency Management Systems and Enforcement efforts. Components managed by TranStar include:

- 160 Mile Freeway Management System, out of projected 300 miles;
- Freeway and Arterial Street Incident Management;
- Ramp Metering at 97 Ramps;
- 190 Closed Circuit Television (CCTV) Freeway Cameras;
- Variable Message Signs;
- 86.4 Mile HOV Lane System, out of projected 105 miles;
- Regional Traffic Signal System of 2,800 Signals;
- Intelligent Transportation Systems (ITS) Programs; and,
- Emergency Management Operations for Evacuations and Disasters.

### ***Staffing***

The unique feature of TranStar is its integration of agency personnel and responsibilities into a single unit that creates a seamless implementation effort. Unlike other transportation management centers, Houston TranStar has combined transportation and emergency management personnel. This integrated structure creates an effective environment in terms of responsiveness, elimination of administrative and boundary constraints and pooling of financial, personnel and equipment resources. For each participating agency, TranStar provides the opportunity to aggressively focus on implementing transportation and emergency management functions.

Initial reaction from staff members of all the departments in the jurisdictions combined to form TranStar was skeptical especially from those staff who felt threatened by the change. However, these attitudes when understanding that the deployment of ITS services would be accomplished with substantial funding, changed considerably to one of acceptance. The implementation of this form

of regional authority over traffic management has, in fact, been accepted willingly by staff members who have been won over by demonstrating the efficiency of regional signal timings.

## **Operational Issues**

### ***Timing and Optimization***

The Traffic Signal Section determines all decisions regarding signal timing and optimization. The Regional Computerized Traffic Signal System (RTCSS) includes the supervision, design, and construction of all traffic signal improvements. The RCTSS permits signal preemption for emergency vehicles as well as coordinated priority signal operation for buses that need to maintain schedules.

The successful operation of signal systems within the TranStar operating area has in fact led to the development of a an Advanced Transportation Management System (ATMS) including a computerized signal system responsible for the management of 2800 traffic signals, CCTV, VMS, and other highway and transit ITS technologies. Houston TranStar is truly integrated in terms of both systems and daily management of personnel and work functions across jurisdictional boundaries. The general feeling is that TranStar has the correct "vision" but it is not as far along as agency members hoped for in its deployment. Each jurisdiction has the ability to view each other=s timing and coordination parameters but since the system is password protected no timing changes can be made by anyone other than the jurisdictional owner.

### ***Data Collection & Analysis***

Within TranStar, the department responsible for these needs is the Planning and Development section. This section has three units, Traffic Signal Systems, Traffic Planning & Engineering, and Systems Integration. Traffic Planning & Engineering is responsible for data requirements. TranStar relies on a range of sources for data collection. Data stations operated by each member agency, including TxDOT, contribute traffic loop data B volume, speed, & occupancy B that is used in determining basic signal timing parameters. In addition to the data stations, there is a traffic monitoring system designed and developed by TxDOT and Amtech Transportation Systems Group. This monitoring system uses vehicles equipped with transponder tags as vehicle probes.

### ***Maintenance***

All maintenance responsibilities fall within the jurisdiction of TranStar staff and the political divisions within the organization. This integrated structure in terms of both systems and management functions across jurisdictional boundaries. This integrated structure creates an effective environment in terms of responsiveness, elimination of administrative and boundary constraints and pooling of financial, personnel, and equipment resources. For each participating agency, TranStar provides the opportunity to focus on implementing transportation functions.

### ***Prioritization***

Setting of priorities for signal issues are made at the staff level with final approval coming from the Houston TranStar Executive Board. In interviews, the technical staff indicated that they could not remember last when a proposal was turned down. The typical delays inherent in the development, design, procurement, and deployment still remained but general opinion was the process has and continues to improve. Due to the recent deployment date of TranStar it is too early to determine after implementation performance measures, however initial evaluations from federal evaluators proved positive.

## **2.3 LAS VEGAS AREA COMPUTER TRAFFIC SYSTEM (LVACTS)**

### **Political Issues**

#### ***Organizational Structure***

LVACTS is a regional authority that has its own offices located in downtown Las Vegas. The system manager is Jerry DeCamp, PE, who has been the system manager since 1990. LVACTS has a staff responsible for signal operations including communications, interconnect etc. Mr. DeCamp reports to the LVACTS Board comprised of members from each jurisdiction. Interlocal agreements between each agency are the legal instruments that form LVACTS.

In the mid 1980=s three jurisdictions agreed to operate their signal systems as one. Thus the beginning of The Las Vegas Area Computer Traffic System (LVACTS). Now, the system membership is comprised of membership from the following agencies

- Clark County;
- City of Las Vegas;
- City of North Las Vegas;
- City of Henderson; and,
- NDOT.

With support from the Nevada Department of Transportation in staffing and equipment, and agreement among the local agencies, the LVACTS was formed. A Board whose members are representatives at the Public Works Director level of the member agencies manages the system. The board assembles once a month to discuss issues relevant to the operations and maintenance of signal systems under its administration.

### ***Location***

LVACTS has separate quarters from the other member agencies. The offices are located in downtown Las Vegas under one of the freeway overpass structures, in NVDOT right-of-way. The use of a separate facility and dedicated staff allows the objective of LVACTS to be visible in its performance of its valuable mission. The LVACTS separate location is praised by agency staff as cutting bureaucratic delay. Without a central location there was a general feeling both from LVACTS and member agency staff that the decision making process would be much longer than having LVACTS function as a multi-jurisdictional bureau operating from a central location.

### ***Cost Sharing***

Cost sharing is determined by formula, after the basic rate structure is determined initially after a division of fifty (50) percent from the City of Las Vegas and proportionately from the other member agencies. Agreement formulas include functions such as number of signals under LVACTS control. Annual funding for LVACTS is proposed to the Board for approval for a fiscal year. The partnership is managed under inter-local agreements designating the contractual terms of operation.

### ***Jurisdictional Responsibility***

Each member agency is responsible for the input of general timing parameters such as minimum green times, walk/don't walk times, etc. Each jurisdiction is also responsible for all maintenance activities, and LVACTS is responsible for the adjustment of coordination parameters. The communications network, comprising a hybrid system of microwave radio, twisted pair, and telephone drops, and the data collected is also the responsibility of LVACTS. Each agency determines equipment selection. Therefore, the responsibilities for each jurisdiction are different than that of TranStar. Agency staff is extremely happy not having to answer questions from the general public. Any complaints regarding signal coordination parameters are the responsibility of LVACTS, however legal liability issues are determined by each agency.

### ***Scope of Authority***

The LVACTS operates as a true multi-jurisdictional traffic signal control system, controlling signals in all jurisdictions in the Las Vegas area, including state highways, from a single Traffic Management Center (TMC). As stated previously, each jurisdiction will determine basic timing parameters with coordination data being the responsibility of LVACTS.

Should there be a communications failure or other system malfunction the LVACTS will troubleshoot the problem. Should the problem be simple, adjustable through front panel entry, then LVACTS technicians will take the appropriate measures. Should the problem require member agency assistance then those actions will also be undertaken. Both LVACTS and member agencies praise the current system.

### ***Staffing***

LVACTS currently has a staff of 12, comprised of engineers, technicians, and administrative support staff. The System Manager reports to an Executive Board comprised of membership from each participating agency. Decisions, technical and administrative, are determined by the Board whose members are at the Public Works Director level, while Board meetings are generally represented at City Traffic Engineer level. All benefits and payroll are handled by the City of Las Vegas, as a part of their responsibilities under the agreement.

## **Operational Issues**

### ***System Configuration***

Currently the LVACTS operates a centralized control system capable of administering 525 signals through the variety of communications media described above. Although there are more than 525 signals in the region, any new signals have to be classified as critical or not to the system. If deemed critical, then another intersection determined to be of less critical value will be dropped from the system.

However, LVACTS is undergoing a system upgrade to deploy Gardner Systems *icons* distributed architecture traffic control system with real time control and intelligence at the intersection level. In addition, communications will be managed at hubs, while report display and database management takes place at the TMC. The new system will also be the first full-scale deployment of 750 new 2070 Advanced Traffic Controller (ATC) with upgrades to existing NEMA cabinets with 2070N software version.

The communications network is also being upgraded while remaining a hybrid system as stated previously. This will see the first time use of 18GHz analog microwave communications for a traffic control system. The system is designed in a ring topology as the backbone for the communications system. Within the variety of communications media used are twisted pair copper, 31 GHz microwave, 900 MHz data radio, and fiber-optic cable.

### ***Timing & Optimization***

The basic timing parameters, such as minimum times, cycle lengths, splits, etc, are determined at the agency staff level while coordination parameters are determined by LVACTS and after agreement with the affected agency then the coordination parameters are downloaded. In theory, the system member agencies write the timing data sets without coordination plans, which are then copied, sent to LVACTS, and downloaded. Interviews with both LVACTS and member agency staff found the arrangement extremely satisfactory. Local agency staff performs timing of new signals with coordination adjustments by LVACTS.

### ***Data Collection & Analysis***

Sampling stations from each agency as well the introduction of ITS technologies form the basis for current data collection methods. NVDOT and the Regional Transportation Commission provide data to the system. Each agency performs their own analysis to determine whether new signals are required either as a result of development, special event, or warrant investigation as the result of citizen action. Collection of data and the resultant analysis for coordination are performed by LVACTS and if changes are required program cards are rewritten and downloaded from the LVACTS.

The implementation of Gardner=s *icons* system will allow for the collection of more timing parameter data, given the greater number of inputs to the system. This greater volume and real time data will allow for more accurate programming of coordination parameters. LVACTS and member agency staff all expressed eagerness and anticipation as they await the full implementation of the *icons* systems and the extended control that its implementation will bring.

### ***Maintenance***

Ownership of the local control equipment remains with each member agency, as does the maintenance of the field equipment. Design and maintenance is performed by each agency. By using this strategy, the LVACTS allows maintenance responsibilities to remain with each agency. However, since LVACTS staff requires access to controller cabinets and communication hubs, they in fact are contractually responsible for the preparation of programming cards.

The System Manager and agency staff all agree that current agreements for operations and maintenance will be reviewed after full deployment of the *icons* system. However, this is not the result of a dysfunctional operation but a determined effort to improve the overall system performance and improve the customer service response for residents and visitors to the Las Vegas area.

### ***Priority Setting***

All strategic decisions regarding system applications and procurements are determined at the Board level while operational decisions by LVACTS staff with input from member agency staff are effected. The fiscal charter of LVACTS allows for increases in the agency=s budget but the Board cannot alter the divisions of funding percentage as defined in the agency=s charter. All staff interviewed (both agency and member agency representatives) were in agreement with the inter-local agreements, and that they did not hinder staff=s ability to determine the system=s needs and prioritization of these needs.

## **2.4 DENVER REGIONAL TRAFFIC SIGNAL IMPROVEMENT PROGRAM (RTSIP)**

### **Political Issues**

#### ***Organizational Structure***

The Denver Regional Council of Governments (DRCOG) is comprised of 48 member government agencies including Adams, Arapahoe, Jefferson, and Boulder Counties as well as the Cities of Denver, Aurora, Boulder, and Lakewood.

The RTSIP is managed under the auspices of the DRCOG. The system was initiated by the DRCOG as a regional tool to better manage the increased traffic volumes being generated by growth in unincorporated county areas. Foremost among concerns was the lack of agency coordination among adjacent agencies as well as a "big brother" attitude from State DOT staff. These concerns were a central theme of those agencies either managing a regional system, or contributing to it.

However, DRCOG staff allocated federal air quality funds, Congestion Management Air Quality (CMAQ) funds, and went to work on regional traffic signal timing issues. Among the issues studied were regional equipment compatibility, cycle lengths, and other mutual and common issues among signal operating agencies resulting in the preparation of a Proof of Concept Proposal, that outlined regional benefits.

### ***Organizational Structure***

The RTSIP is comprised of representatives from those agencies with membership in the DRCOG. Each agency still retains autonomy of their signal control but implements timing plans generated by DRCOG staff. This arrangement is executed under local agency agreements mandating the DRCOG to implement boundary crossings as well as manage traffic on principal and major arterials where traffic flow is critical. All participants interviewed expressed cooperation and willingness to cooperate with DRCOG in management of critical roadways. Member agencies retain liability over those intersections that comprise the regional network.

### ***Cost Sharing***

The RTSIP is fully funded by CMAQ funds. Funding is on a pro rata basis and the committee audits its own operation to determine cost allocation. Approximately seventy percent of funding is allocated to field improvements and the remaining thirty percent on administration and engineering. The DRCOG staff prepares programming cards which are then entered by the appropriate agency. All tasks are conducted in a team framework reflected in both technical and management capacities.

### ***Jurisdictional Responsibilities***

Each member agency retains autonomy over their own traffic signal systems including system maintenance. Member staff interviewed expressed support for the system and generally were pleased by performance of staff and thought the inter-local agreements served the public well.

### ***Scope of Authority***

The DRCOG staff, as managers of regional signal timing, work very closely with their counterpoint agency staff. They determine basic corridor timings and also prepare the coordination programs for regional arterials. DRCOG staff manages and responds to system complaints. As with the majority of multi jurisdictional coalitions, individual agencies may have biases but as the program undergoes analysis, its responsibilities on freeway and arterial signal systems are updated every three years.

### ***Staffing***

DRCOG staff staffs The RTSIP. Stakeholder and technical committees are comprised of agency traffic engineer level staff from DRCOG members. Implementation of system parameters is by DRCOG operators and maintenance staff. RTSIP staff performs functions such as system and corridor studies, preparation of Plans, Specifications and Estimates (PS&E) as well as timing and optimization.

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## **Operational Issues**

### ***System Configuration***

Currently, the system is comprised of a series of closed loop systems operated by each member agency. Data needs are managed by DRCOG and the data collected is modeled, including simulation modeling, managed by DRCOG. The output generated is input with program cards developed by DRCOG staff. The system is currently undergoing a migration to a distributed system architecture with two TMCs. Final configuration is undetermined at this time.

### ***Timing & Optimization***

Timing parameters for the identified corridors in the metropolitan Denver region are developed by DRCOG staff and implemented by member agency staff. Most timing plans are generally Time of Day (TOD) programs covering peak hours and a third off-peak hour. Other special event optimization was implemented as necessary. Staff reaction to the structure was positive and customer service oriented with eagerness to deploy a state-of-the-art signal control system.

### ***Data Collection & Analysis***

RTSIP staff manages the data collection taken among sources from sampling detectors of contributing systems. In addition, staff perform before and after studies to quantify benefits and determine measurable improvements. It is important to note that CMAQ funding does not apply to ongoing signal operations and maintenance.

### ***Priority Setting***

As with most dedicated federal funds, CMAQ funds have benefit reporting requirements that include signal timing as an approved benefit. Also, as part of the benefits reporting requirements, priority falls on Capital Improvement Projects. The selection of the projects after CIP projects is based on engineering judgement. Implementation reviews have found that "after" studies revealed that not all timing and optimization parameters were implemented.

## **2.5 CONCLUSIONS**

Downstream from the consultant team's presentation, subsequent meetings of the Steering Committee lead to the pursuit of the Las Vegas model of operation as the preferred target operational structure.

Further refinement of agency responsibilities, funding mechanisms and other administrative structure elements will be the task of the Steering Committee while this study focuses strictly on the technical aspects of a regional system.

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## 3.0 Signal System Inventory

### 3.1 INTRODUCTION

This chapter discusses the current status of the Geographic Information System (GIS) database and associated traffic signal infrastructure information. The objective of this chapter is to report the traffic signal system information that was collected and incorporated into the GIS database. This section will also present some of the existing data relevant to signal controller age, signal controller type, and signal maintenance.

### 3.2 GEOGRAPHIC INFORMATION SYSTEM (GIS)

One definition for GIS is a decision support system involving the integration of spatially referenced data in a problem solving environment. GIS is not map creation software, but is a process that is best utilized when analyzing information that includes spatial and attribute data. Applications for GIS include fire department routing, military troop movements, cellular tower placement, local government growth plans, business marketing, police crime tracking, and transportation-related uses such as highway and transit planning and inventory management. In many problems, spatial and attribute information needs to be analyzed together to effectively develop solutions. A GIS allows one to store, manage, and analyze spatial and attribute information.

A GIS is needed in this study because the spatial location of each signal is crucial to analysis and decision-making as well as the attribute information associated with each signal which influences conclusions, feasibility, and decisions. Not only will the GIS provide for a current signal system inventory, but will also aid in coordination feasibility, inter-jurisdictional compatibility, and corridor analysis.

The GIS software used in this study is ArcView version 3.1. The signal data obtained from the jurisdictions and agencies were entered into its database, the signals were placed in their correct locations, and then the two types of information (attribute and spatial) were linked to represent each signal. With the information entered into ArcView, spatial/attribute analysis is possible as well as creation of presentation materials such as maps and plots.

### 3.3 DATA COLLECTION

A request for traffic signal information was sent to each of the participating jurisdictions/agencies on June 9, 1999. Each jurisdiction/agency was responsible for collecting and providing the information for the given signalized intersections in their respective areas. The consultant team then compiled these data into a database that was linked to the ArcView software. The types of traffic signal data gathered are listed below:

- Jurisdiction,
- Signal Controller Brand (e.g., TCT, Eagle, Multisonic),
- Signal Controller Model (e.g., 8811, EPAC 300, 820A),
- Signal Controller Installation Year,
- Number of Phases in Operation,
- Operating Mode (e.g., fully actuated, semi-actuated, pretimed),
- Detection Type (e.g., loops, video),
- Preemption (e.g., fire, rail),
- Control Cabinet Type,
- Control Cabinet Installation Year,
- Signal Controller Type (e.g., NEMA, 170, Electro-Mechanical),
- Agency or Jurisdiction that Maintains the Signal,
- Interconnection Type (e.g., physical interconnect, time based coordination),

- Interconnection Media (e.g., copper wire, fiber optic, etc.),
- Interconnection Location (e.g., direct burial, conduit, overhead),
- Conduit Type (if applicable),
- Conduit Size (if applicable),
- Number of Copper Strands (if applicable),
- Fiber Optic Type (if applicable),
- Field Master Signal Control (Node ID number), and
- AM, PM, or Off-peak Cycle Lengths.

### **3.4 GIS DATABASE**

The data for each signal location was then entered into the database. Each record in the database represents one signal and contains its associated data in respective fields. The intersecting roads for the signal location had already been provided and entered into the database. The signals were assigned individual Node ID numbers and Corridor ID numbers to represent the signal and its location on a particular MARC corridor.

Some signals involved the intersection of two MARC corridors. In these cases, the signal was assigned a Node ID number as usual, but only one of the two possible Corridor ID numbers was applied to the signal. However, an identical record was then created in the database to represent the fact that the particular signal could be considered as part of the other corridor. This alternate record was then assigned the negative value of the Node ID number associated with its original record. Some alternate records may have been included even though the signal may only be considered for the study with respect to one of the intersecting corridors. A hardcopy of the database is included in Appendix D.

## 3.5 GIS SPATIAL REFERENCING

The next step was to represent these signal records spatially within the framework of the GIS software. A point was used to represent each signal and its associated information (i.e., one record in the database). A road network theme was obtained and used to place the points representing each signal location. The alternate records, which have negative Node ID numbers, were not spatially represented since this would entail two points representing the same information being placed at the same location. Therefore, the alternate records are included in the database only, and will be useful for future corridor analyses.

In order to provide a greater analysis capability, the segments of roads connecting two signals were registered in the GIS software. When registered, each segment would have signal and traffic information associated with it:

- Signal origin and terminus (crossroads and Node ID numbers);
- Length of the segment connecting the two signals; and,
- Any traffic count data that was associated with that segment.

The segments were used to incorporate signal interconnect information. This additional information concerning signal interconnection was also requested from the jurisdictions/agencies in order to be applied to the segments created. For the segments that had interconnect between two signals, the segment was assigned an Interconnect ID number. Therefore, groups of interconnected signals will have the same Interconnect ID number. The collected interconnect information can be displayed in ArcView with the most basic function being that of highlighting which segments involve interconnected signals.

## 3.6 RESULTS

ArcView was used to present the following traffic signal information: signal controller age, signal controller type, and signal maintenance. The plots display the signals as points, color-coded according to the legend and what information is being presented.

Three exhibits have been included at the end of this section showing signal controller age, signal controller type, and signal maintenance. Each exhibit is a regional plot which shows the results and statistics for all of the jurisdictions in the MARC Region. The regional plot is designed to give an overall view of the area. Figure 1 presents signal controller age results, Figure 2 shows signal controller type information, and Figure 3 displays signal maintenance information.

For clarity purposes the road network shown in the plots does not display minor streets and roads in the areas. However, some minor street signals have been included in the analysis on behalf of some of the jurisdictions, and therefore these signals may appear to be located where no streets appear to be present. Additional plots can be produced which would show the entire road network if needed.

Unfortunately, not all data received was usable, and some data was not received at all. Thus, the plots do contain signal locations where specific information could not be shown. These signals appear black on the plots, and their percentage of the total signal inventory is shown in the exhibits.

### ***Signal Controller Age***

The regional plot for signal controller age shows that 21.2% of the signal controllers in the inventory are five years old or less. About a quarter of the signal controllers (24.7%) are six to ten years old. The majority of the signal controllers (48.2%) are more than ten years old. The plot shows that a majority of these older signal controllers are located in Kansas City, Missouri. This information may have skewed the overall statistics, in that Kansas City, Missouri provided installation years based on the traffic signal installation as opposed to the signal controller installation in most cases. A small portion (5.9%) of the signal inventory had incomplete data regarding signal controller age.

The signal controllers in Lenexa were all installed sometime in the 1980s and 1990s. Their contributing percentage was distributed accordingly between the time span divisions used in the plot.

### ***Signal Controller Type***

The signal controller types were classified as NEMA, 170, or Electro-Mechanical. The 170 type signal controllers were the highest percentage at 35.8%. About 31% (31.1%) of the signals inventoried had NEMA type controllers. A small percentage (4.3%) of the signal controllers were Electro-Mechanical. If the signal controller type was not specified in the data collected from the jurisdictions/agencies, then the controller type was based on the brand and model of the signal controller. However, in some instances the signal controller brand and model information was incomplete as well. These instances are noted in the database by a "?" in the category of Controller

Type (a blank in this column means no data or very little data was received for that particular signal/record). Therefore, a fair number of signals (25.3%) have inadequate or no data concerning signal controller type.

### ***Signal Controller Maintenance***

An overwhelming majority (91.2%) of the signals in the database are maintained by the jurisdiction/agency in which they are located. The next highest percentage is 6.7%, which represents signals whose maintenance is contracted through another company or agency. The jurisdictions of North Kansas City and Raytown have maintenance programs that allow some signals to be maintained by contractors and some to be maintained by the agency. It should be noted that these signals constitute only a small percentage (2.1%) of the signal inventory.

# FIGURE 1 – SIGNAL CONTROLLER AGE

## FIGURE 2 – SIGNAL CONTROLLER TYPE

## **FIGURE 3 – SIGNAL MAINTENANCE DATA**

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## 4.0 System Objectives

### 4.1 INTRODUCTION

The foundation of a traffic management system is based on a realistic identification of the objectives of why a system is being developed for a region. The mission is to answer the question "What do we want the system to be able to do?"

In order to extract that information from a diverse group of several members, a project workshop was held September 9, 1999 at MARC offices to determine what the objectives of the system ought to be.

The consultant team presented a variety of issues necessary to be considered. The discussion quickly became dynamic with several agencies voicing their specific viewpoints and needs. After deliberation, the group participated in an exercise to refine their ideas and prioritize system objectives.

### 4.2 SYSTEM OBJECTIVES

Nine system objectives were identified for the MARC advanced traffic management system (ATMS) based on the functional requirements and discussions with the Technical Advisory Committee. The system objectives are listed and described below:

- ***Simplified Database Management*** - This system objective includes: timing data (for both local intersection controllers and field masters), data collection, alarm reporting and inventory programs (signing, pavement marking, maintenance, etc.).
- ***Improved System Monitoring*** - This includes: usable data summaries (volume, occupancy, speed and other measures of effectiveness), event reporting, equipment status and video surveillance.

- ***Increase Operational Flexibility*** - This objective includes: control methods (time of day, traffic responsive plan selection and special events), variable signal control groups, flexibility of developing and implementing timing plans (e.g. 1.5 generation). It also includes the ability to implement other ITS activities (e.g. link to FMS, CCTV, VMS, etc.).
- ***Cross-Agency Coordination*** - This objective relates to the ability to provide coordinated traffic movement across jurisdictional boundaries.
- ***Provide Modularity/Expandability*** - This includes: system size flexibility, communications options, readily available hardware, software enhancements, and software longevity projection.
- ***Enhanced Maintenance Capability*** - This system objective includes: failure identification (central and field equipment), equipment reliability, local service, standardize equipment, and backup.
- ***Individual Agency Timing*** - This objective relates to the ability of an individual agency to develop and implement their own timing plans.
- ***Ease of Operation*** - This objective includes: good user interface, advanced graphical capabilities, and windows-based operating system.
- ***Multiple Controller Opportunity*** - This system objective includes: direct communication with various controllers, Type 170 and NEMA compatibility, NTCIP compliance, and not requiring an interface unit.

### 4.3 CONSTANT-SUM PAIRED COMPARISON (CSPC)

The above listed system objectives were prioritized using the Constant-Sum Paired Comparison (CSPC) technique. This technique compares each system objective with every other system objective on a one-on-one basis. The results of a CSPC show the relative importance of each of the nine system objectives.

In CSPC evaluation, each of the nine system objectives is paired with each of the eight other system objectives. This results in a matrix with 36 pairs. For each pair, a total of 20 points are divided between the two system objectives based on their relative importance. For example, in a given pair, if the first system objective is three times more important than second system objective, then 15 points are assigned to the first system objective and 5 points are assigned to the second system objective. Any combination that adds up to twenty points per pair can be used as long as a zero is not assigned to either system objective. The points received by each of the nine system objectives are accumulated. The system objective that receives the least number of points is assigned the weighted rank  $A1.00$  and the other system objectives are assigned weighted ranking relative to the points they received. For example, if the least important system objective received 100 points and the most important system objective received 162 points, the weighted rank of the most important system objective is 1.62 (162/100).

#### **4.4 ESTABLISHING MARC SYSTEM PRIORITIES**

In order to prioritize the nine system objectives for the MARC ATMS, CSPC was administered to the Technical Advisory Committee. The CSPC evaluation provided the weighted ranking (relative importance) of the nine system objectives by individual members of the Committee as well as a composite ranking of the nine system objectives for the entire Committee.

The individual weighted ranking (individual priority) of the system objectives is based on individual responses to the CSPC evaluation matrix. The composite ranking (Committee priority) of the system objectives is based on aggregation of the individual responses. A spreadsheet was prepared to record individual responses and to determine the Committee's response by aggregating the individual responses.

#### **4.5 CSPC EXERCISE RESULTS**

The individual weighted ranking of system objectives resulted in a group representation of the priority of the system objectives. Based on the numerical results of this exercise, the objectives fell into the following three categories:

**High Priority:**

- Increase Operational Flexibility;
- Improved System Monitoring; and,
- Cross-Agency Coordination.

**Medium Priority**

- Enhanced Maintenance Capability, and
- Provide Modularity/Expandability.

**Low Priority**

- Ease of Operation;
- Individual Agency Timing; and,
- Multiple Controller Opportunity.

Committee members had a wide difference of opinion for the importance of "Simplified Database Management." The Committee's weighted ranking of system objectives indicated that "Increased Operational Flexibility" with 1.62 points was the most desirable feature and "Multiple Controller Opportunity" with 1.00 point was the least desirable feature for the MARC ATMS.

The low ranking of "Multiple Controller Opportunity" is interesting and was the subject of further discussion by the Technical Advisory Committee. This could be interpreted several ways. Although NTCIP communication protocol is intended to provide multiple controller communication it is not yet fully functional and there are compromises when trying to communicate with different controller types from a central ATMS. The old central control system (e.g.UTCS) have the ability to control various controllers, however the distributed control systems tend to be controller specific.

The sheets in Appendix E show the relative ranking for the entire Technical Advisory Committee (heading indicates "CSPC – Team") and individually for each member.

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## 5.0 System Elements

### 5.1 INTRODUCTION

This chapter summarizes the workshop discussions conducted in October, November and December of 1999 with the Technical Advisory Committee (TAC) to determine the desired elements of a regional traffic management system. That discussion began with a review of the previously identified System Objectives (Chapter 4 of this report), as a basis. The objective was to identify reasonable system elements that support or lead to successful accommodation of the system objectives.

As the discussions began, the discussion leaders emphasized the need to keep in mind not only daily traffic flow, but to also consider impacts and support of traffic operations and maintenance activities.

An exercise was conducted after the November Workshop to determine the importance of each category of elements, and the specific sub-elements within each category. The presentation of the following sections represents the order in which the numerical results of this exercise would rank the importance of the elements categories after accounting for all agency=s input. In the case of any agency having more than one representative provide input, the input of that agency was averaged before being included in the total. Thus, no agency had an undue advantage in influencing the order of the elements categories when more than one representative of the same agency provided a ranking.

### 5.2 Signal Monitoring and Data Exchange Features

The entire group agreed that their common goal was to make sure the system provided the capability to time the main corridors throughout the region in a manner that provided the best traffic flow possible. Certainly, the hardware cannot do this without human intervention. Thus, this discussion attempts to define the type of system hardware solution necessary to support the desired result. Somewhere downstream of system implementation, human beings must develop strategies for signal phasing and signal timing consistent with providing good traffic flow.

There was a strong desire for multiple agencies to view each other's timing plans on-line, but not necessarily have the ability to modify or download changes. The desire to view what is happening at all signals in the region is not uncommon in a multi jurisdictional area. However, due to jurisdictional policies and fear of litigation, most agencies are not anxious to allow others to have access to the ability to change on-street operations.

In the case of the Kansas City region, however, the formation of a Regional Authority may result in some level of multi-agency ability to change signal data, but under a very restricted structure with multiple safeguards. The details of the final structure of the Regional Authority and its corresponding powers is not a part of this study, but is ongoing in parallel as the mission of the Steering Committee. The TAC did express interest in cooperating with a regional authority so that the operation of signals on the main corridors can be coordinated to best facilitate the current traffic operations. Some even went so far as to desire the regional authority take responsibility for all signals, including those not located on a main corridor because it would be more advantageous to the public and the local entity, given the existing level of signal operations capabilities.

In the event changes to local signal timings are allowed by the regional authority, the local agencies did desire a system configuration that would log what changes were made, when, and by which user or if the change was implemented in the field.

One evolving industry standard that the TAC insisted on is the use of the National Transportation Communications ITS Protocol (NTCIP) communications protocol between the traffic management center(s) and the field devices. The NTCIP protocol has been under development for several years, and a standard does exist as a National Electrical Manufacturers (NEMA) publication. However, adoption and integration of this protocol has been painfully slow by controller manufacturers for various reasons, including some unanticipated overhead burdens of the protocol itself, and the final approach to implementation will depend on the status of the protocol when this system is finally deployed in the Kansas City region.

### **5.3 Detection Features**

The ability to detect traffic is essential in a regional system. It allows the operators to monitor traffic flows through field feedback of measures of effectiveness described earlier, such as speed and volume, and they provide input to the local controller for manipulating the signal sequence and green displays.

Discussions with the TAC indicated an interest in a system which, assuming the local loop wiring and cabinet configuration can discern separate channels or loops, identify a loop channel that has had an unusually long presence or lack of presence (user defined), notify the system operator, and offer a timing resolution to the perceived fault until such time human intervention can be provided.

The theory is that if loops are failed, certainly human intervention and verification is still necessary. However, loop problems can be more quickly identified because they will report themselves, and the standard resolution of adjusting phase timings to accommodate for faulty loops until they are replaced (sometimes months from initial discovery) can be immediate.

The system should also be capable of adjusting algorithms for alternate forms of detection, such as RTMS (radar), microwave and microloop technologies so that deployment of any of these alternatives to standard loops does not render the ability to continue to gather MOE data inactive.

## 5.4 Security Features

System security is a concern for any public agency, and especially so for a system that has legal implications on public safety. As a group, the TAC expressed some frustration with existing levels of security, and look for this opportunity to help tighten up security measures and reduce exposure to liability potential.

A common problem almost every agency in the US has experienced is unauthorized personnel gaining access to the local controller cabinet and placing the signals to flash operation. This is most often done in a well-meaning attempt by the local law enforcement agency to facilitate traffic flow. Many times it may be an appropriate operation, but a general lack of communication with the agency responsible for signal operations tends to occur, resulting in frustration.

Less commonly, other entities such as contractors, transit operators, organizers of special events or sports venues have been involved in similar circumstances.

Modification of local timing parameters has been a less frequent issue, if manifested at all, thanks to the data entry procedures and security features offered in modern controllers.

As a measure intended to address the local flash issue, the TAC desired a security feature that provided feedback to the central system of when the door was opened or when the signal was placed in the flash mode via the police panel or cabinet flash switch. The door is generally monitored by

a pressure switch on the door frame or a switch linked to the cabinet light switch (which is also a door frame switch).

The controller can be instructed to report a flash condition if the cabinets are wired to report such conditions to the controller. However, the distinction of whether the flash event was caused by the police panel switch, interior cabinet flash switch, software programming (planned late night flash is an example) or caused by the conflict monitor is a more difficult sorting process and will have implications on cabinet wiring design for participants who wish that level of reporting.

After the intersection is brought out of the flash condition, and back into normal operation, that event is desired to be reported back to the central system operator, and transmitted to the owning agency. Not all agencies need to receive that logging event, in the interest of reducing log event clutter.

At the system level, not all users should be allowed access to all data. More importantly, not all users should be allowed to change data through the system. Assuming that eventual evolution of access to traffic data follows similar evolutions that have already occurred around the country, the public may be allowed limited access through the Internet. Linkages are envisioned to the local freeway management system. Other new systems, that have not been defined yet are possible. All of these linkages to the "outside world" need to be secure and protect the traffic management system from data loss or manipulation.

Another system level security tier involves the traffic management center itself, if one or more are constructed. At the lowest level, a user agency with a PC on a desktop in an unsecured office allows opportunity for access, with only the password for system protection. At the high end, a dedicated traffic management center control room should be secure to unauthorized entry. In fact, this is probably one of the most important security tiers because system documentation and records exist in paper form, and a skilled individual intent on breaking into the system is actually facilitated if they gain access to those materials.

## **5.5 Maintenance & Operations Features**

The TAC identified two areas of interest that would support maintenance and operations staff, making their daily jobs easier, allowing them to spend more time controlling traffic and optimizing traffic flow.

One area of interest was the ability of the system to support an integrated Work Order system. This system would log on-line any work orders related to system operation, issued or handled by any participating agency or the Regional Authority. Participating agencies could then call up an intersection, view linkages to a work order database, and view a work order history to determine when changes were made and by whom.

Of course, the accuracy of this system would rely heavily on technicians providing such documentation to the system. Automated means of filling out and posting work orders are available in the marketplace to further automate this function at the technician level.

A second area of interest was the ability for the system to link to a signal equipment inventory database. This database would include specific information on signal equipment, poles, controllers and other selected localized features. Current systems available in the marketplace also allow the use of photos (.JPG files) to be included in the database, but at the expense of significant memory or storage capability.

## 5.6 Logical Linkages

As eluded to in the prior section regarding system security, certain linkages to outsiders and other systems will occur. There is a possibility for other linkages, not yet envisioned, over time.

The most obvious linkage the system shall provide would be a communications link to the regional freeway management system (FMS) for the purpose of integrating on and off-freeway operations into a seamless operation. In this region, the SCOUT system is such a management tool, and is currently under development. This can take the form of total integration, where operators on one system have full functionality on the other, or it can be at a less robust level, where operators of one system can at least view the operation of the other system, but must manually contact a human at the other system for intervention in reaction to incidents or congestion.

In the case of the Kansas City regional FMS, there is always the possibility of freeway operations causing the need for rerouting traffic onto surface streets during an incident. The opposite, although much less likely, is also possible. As such, the regional traffic management system should consider providing at a very minimum, a workstation or integrated linkage for viewing surface street traffic operations (data and video images). In the event of an incident, the FMS operators will be able to determine areas of congestion, additional congestion caused by the incident, and use that data to reroute traffic at multiple locations impacting surface street traffic operations.

Although a complete Operations Plan has not been formulated at this time, at some point specific policies and coordination structures will need to be defined between the FMS and local agencies to predefine how such matters will be dealt with, who deals with whom, and who has the rights to change operating parameters.

Likewise, this concept is a two-way street. As such, the regional traffic management system operators and participants should be able to view traffic operations on the freeway, including video images. This information will be equally useful to the surface street operators to anticipate where to adjust signal operations to accommodate additional traffic, allow the capability to monitor the incident via the video feeds, and readjust operations during the course of and recovery from the incident.

Internet access to traffic data is a desirable feature, to the extent that the Internet connection can be guaranteed secure from violation resulting in data manipulation. Typical Internet exports include a regional map with color codes indicating where traffic flow is slower than expected, mpeg video feeds from video observation cameras at critical intersections and e-mail links to the traffic management center for reporting traffic problems or questions. This single element has helped gain tremendous public support and evidence that their tax dollars are hard at work trying to deal with traffic.

The above Internet style connection is also desirable, even more so than to the general public, to local media responsible for reporting traffic conditions to the public. The same type of connection can be used, with security features allowing only authorized personnel access to the site or data. In some locales, media personnel are present in the traffic management center during peak periods, giving the public the perception that the media and traffic management entities are in collaboration for the mutual benefit of the traveling public, and linking traffic management with immediate public information.

Other future linkages that may be desirable in the future may be to the local transit operators, police, fire and ambulance operators. Some TMC=s currently have some of each of these entities participating in partnership, offering an additional mechanism for gathering information on where incidents have occurred (from emergency services dispatched to scenes) or for improving other modes of transportation (transit) by offering immediate traffic condition data necessary for evaluating transit schedule adherence and routing.

Another type of linkage, but not a data export or video image type of operation, is the ability to monitor a variety of school crossing signals in the region. Although not truly traffic signals in the strict sense, these devices warrant linkage to the overall system for the purpose of monitoring and possibly even modification of operational parameters.

## 5.7 Measures of Effectiveness Features

Every traffic control system should offer a variety of reports and tracking of statistics and other data that assist the operator in evaluating efficiency of operation. Unfortunately, most off-the-shelf systems provide so many options, the typical operator will settle on a small handful with which they gain a comfort level.

In discussions with the TAC group, it was determined that the level of interest in the system reporting various "measures of effectiveness" (MOE's) was not strong. The consultant team was asked to consider the provision of MOE reporting as a "desirable" feature, but not one that should dominate final system design to the point of the additional cost causing sacrifice of other, more necessary features.

If easily provided, without significant additional cost, the following types of MOE reporting would be desirable.

- **Greenband** - For a user defined segment of roadway, illustrate graphically, in color, the current greenband when the corridor is operating in a coordinated mode.
- **Detector Information** - For user specified loop detectors, connected at the local controller and configured and recognized by the regional system as "system" loops, reporting of volume (vehicles/period of time) and speed (average miles per hour/sample size).
- **Split Monitor** - For a user selected intersection, report graphically, in color, the allocation of green and clearance timings for the various intervals at an intersection connected to the regional system, for a user defined time period.

## 5.8 Video Traffic Monitoring (CCTV)

The use of video to monitor traffic flows has skyrocketed over the last five years. Typically, the use of video is the application of observing traffic conditions at a critical intersection or stretch of roadway.

In the Kansas City region, several critical intersection candidates were identified by the TAC as well as roadway segments, such as the Burlington and Fairfax bridge crossings. However, some reasonable quantity of cameras should be identified and a more detailed Regional CCTV Strategy developed. Limitations do exist, especially if the TMC is expected to have available a full motion feed from each camera at all times for possible selection for viewing.

It can be expected that if multiple agencies all have CCTV capabilities at certain intersections that are important to them, that these feeds may be necessary to be available from the TMC. Another architecture would be to feed each agency's CCTV cameras to their local agency site, and then feed upstream to the TMC. However, given the assumption of a regional authority, and the implication that the regional TMC will drive the architecture of the system, the prior concept of all CCTV feeds linked directly to the TMC, and users accessing the feeds from the TMC is more likely and desirable from a system architecture standpoint.

CCTV equipment should provide pan-tilt-zoom capabilities, and be capable of viewing and being controlled by a participant agency from their own workstation. Aesthetically pleasing devices help conceal the cameras from vandalism and negative public reaction. Typical camera systems provide color images, and are capable of working in all weather conditions, including low light environments.

At the January, 2000 workshop, the consultant team presented a summary of the CCTV exercise conducted in December with the Technical Advisory Committee, as illustrated in Figure 4 on the following page. This plan calls for approximately 250 CCTV sites around the region with a total price tag, just for the field equipment, of approximately \$10 million. Adjustments in quantity and location of specific sites is anticipated over time, in reaction to traffic flow needs, availability of supporting infrastructure and funding availability.

It is strongly suggested that any deployment of CCTV verify that sufficient communications infrastructure be provided for transmitting the video images back to the video central switcher. This consideration will likely influence where CCTV is deployed and in what order of priority. Assuming that the regional freeway system backbone will provide sufficient capacity, CCTV locations closest to the backbone may be the best early candidates.

## FIGURE 4 - CCTV PLAN

## 5.9 Communications System

In order to provide an adequate support mechanism for transmitting data from the traffic signals and video images from the field to any user, some thought is necessary to be invested in what the communications system will be to support communications between the TMC and field devices, as well as in support of the various external linkages discussed previously.

Copper wire interconnect has been the standard for the last 25 years in our industry, and has recently been challenged by the use of fiber optic cables and wireless communications of various varieties.

Typically, the communications system accounts for 50% or more of the cost of any traffic management system. In the case of a region where no significant historical investment in interconnect has occurred at a measurable level, or any such prior interconnect is not in suitable condition to accommodate the task for which it will be needed under the new system design, a significant amount of money is necessary to be dedicated to the communications system alone.

Based on the TAC discussions, it has been determined that there are some areas of the region where copper interconnect had been deployed and may be in suitable condition for reuse if the future traffic management system design is able to utilize the limited bandwidth (data carrying capacity) for the devices envisioned. This will probably work fine for transmission of traffic signal data, at least for the next several years.

The communities of Lenexa, Olathe and the Missouri Department of Transportation (MODOT) have all made some investment in fiber optic cables. This media will support full motion video and very robust data carrying systems, assuming an adequate number of fibers are provided and connectivity between all necessary points is achieved.

No wireless technologies are currently being used to support traffic signal communications. However, wireless technologies do exist in the form of spread spectrum radio, microwave, cellular radio, packet radio and satellite, each with its own issues in terms of cost, bandwidth and data transmission. Wireless communications are especially useful for short term or short distance applications, but many modes are susceptible to environmental interference and may be viewed as slight less reliable than land line methods.

Some concerns were raised by the Technical Advisory Committee regarding the use of antennae for any wireless solution, especially in terms of visual impacts. All of the wireless solutions require antennae of one sort or another.

Spread spectrum antennas can be either omnidirectional or directional, depending on application and physical layout of the area. Omnidirectional antennas look like a car radio whip antenna, of lengths between 18" and 36", depending on frequency range. Directional antennas consist of a horizontal piece approximately 24" in length, with several cross members. Directional antennas are more noticeable because they are more bulky. Both tend to be mounted on mast arms or on signal pole shafts, but are sensitive to line of sight to the next radio in line.

One of the issues regarding spread spectrum radio systems that will need to be examined in detail during the design phase is that radio works best in flat terrain. Although the terrain in the Kansas City area does have hills, radio system designers do have ways to minimize the negative aspects of terrain through the use of repeaters strategically located on high points such as tall buildings, water towers and radio towers.

Microwave systems use a domed dish design antenna, size variable to match frequency. Sizes typical to the traffic industry are 12" to 18" in diameter, and are typically mounted on pole shafts with sufficient line of sight to adjacent antennas.

Satellite systems use dish antennas that resemble a residential satellite TV dish in size and nature. Antennas can be mounted in a variety of manners as long as adequate sight to the southern horizon is unobstructed.

In any case, there is admittedly some level of visual impact, but drivers passing through the intersection have such limited exposure to the opportunity to see these devices that visual impacts have traditionally not been a factor. So many other visual stimuli exist in the urban environment for drivers that antennas are not likely to be noticed unless they are unusually large or mounted conspicuously.

A variety of land line alternatives exist for communications in the traffic management industry. Among these alternatives are copper cable, fiber optic cables, coaxial cable, and a variety of leased lines each with its own characteristics of baud rate, duplexing, cost and maintainability. Considering the data exchange needs of only the traffic signals, and assuming an industry typical baud rate of 1200 or 9600 for data purposes, almost all of the above media are suitable if an appropriate connectivity configuration can be achieved at the design stage.

Once the region wishes to commit to full motion video and CCTV observation, or robust data transmissions, a high bandwidth media, such as fiber optics will be necessary. Since the freeway management system, SCOUT, is already envisioning a fiber optic backbone system with sufficient capacity to accommodate additional users, such as the Operation Green Light elements, the proposed communications topology is based on the use of fiber optic lines linked to the SCOUT trunk system.

Figure 5, on the next page, illustrates a Phase One communications plan for the Kansas City region. It suggests approximately 13 miles of fiber optic communications. If assumed that installation of new fiber and conduit cost on the order of an average of \$22 per foot, the Phase One plan could cost on the order of \$ 1.5 million.

The Phase Two plan, Figure 6, includes approximately 22 miles of new fiber infrastructure, costing on the order of \$ 2.5 million.

The ultimate Buildout plan, Figure 7, adds another approximately 160 miles of fiber at a cost of approximately \$ 18.5 million. The total estimated cost of the fiber plant, for full Buildout, is thus estimated to be on the order of approximately \$25 million, in Year 2000 dollars. These costs do not include the equipment on the ends of the fiber, the costs of which are assumed to be embedded in the field elements costs and traffic management center costs. This cost may be reduced where design makes use of existing conduits already in place for other purposes such as existing interconnect or empty conduits to which agencies have rights from private communications carriers.

Implementation is difficult to plan too far into the future from the field work due to the dynamic nature of communications systems. For example, when funding becomes available for the communications plant, an assessment of the level of completion of the SCOUT backbone will be necessary, since that backbone is what will carry the data and video to the traffic management center, whose specific site will be determined in the future. Since the SCOUT backbone system will encircle the entire region, access to the TMC location, wherever it will be, is assumed to be supported because it will be within reach of that backbone. Linkages to workstations in any of the participating agencies will also utilize the SCOUT backbone, again, easily accomplished due to the circular nature of the system.

Another consideration is the presence of private communications providers who may be leveraged into providing conduits for agency owned fiber. However, agencies are cautioned that the best shared system configuration is one in which the end equipment is owned and maintained by the Operation Green Light group, as opposed to the fiber provider. This can eliminate unforeseen bandwidth and access limitations.

# FIGURE 5 - PHASE 1 COMMUNICATIONS PLAN

# FIGURE 6 - PHASE 2 COMMUNICATIONS PLAN

# **FIGURE 7 - BUILDOUT COMMUNICATIONS PLAN**

Individual linkages within the displayed plans are subject to redefinition as funding becomes available. Thus, the amount of fiber per phase could be thought of as a general quantity, with specific routes keyed to corridors and CCTV locations being implemented at the same time or previously implemented. Other key linkages will be from the SCOUT system over to the workstation locations within each agency.

The illustrated communications plans do not assume usage of any existing fiber owned by any participating agencies, assuming a fully-dedicated Operation Green Light system. At the time of design, if existing fiber is willing to be dedicated by a participating agency and is of sufficient type and quality, and provides the desired linkages, a reduction in capital cost can be expected.

A second strategy to utilize fiber optics along the arterial street network as a connection to the SCOUT system is the use of the cable TV entity's fiber plant, similar to a leased line concept typical of telephone lines. This concept has been used by the City of Overland Park, Kansas, for over 20 years, and has resulted in dependable communications. Although the initial cost per intersection is higher, there is an approximately 6 year time frame for the cable TV approach to balance out against the cost of a typical telephone line installation.

In discussions with Time Warner, the local cable TV entity for all participating jurisdictions except Olathe and Independence, a typical cost per intersection would be \$180 per year plus cost of installation. In Olathe and Independence, it may be possible to extend from the Time Warner system into the ComCast cable TV system through interagency agreement. Likewise, extension into the SCOUT backbone is possible if the SCOUT system is evaluated and determined to conform to the specifications for the cable TV entity.

The current status of fiber optics for the Time Warner system is that the entire region has undergone recent fiber conversion, and that Johnson County is still under conversion. There will be opportunities to use the Time Warner fiber plant to support video images, but the capacity of the infrastructure is unknown at this time in terms of whether the 250 envisioned CCTV sites could be fully supported in a full-motion video scenario.

Maintenance of the Operation Green Light facilities, if on the Time Warner plant, is envisioned to be supported as a high priority given that the cities are viewed as major customers with influence over the other residential and commercial users. Additional leverage is available through the city holding the franchise agreements which give the entity rights to operate within the city limits. In some cases, franchise agreements may call for provision of fiber to the city in exchange for some of the franchise conditions.

The use of the existing cable TV entity has been proven as a viable scenario in the region. It would be worthwhile to analyze and compare the availability, cost and franchise implications for using existing cable TV fiber at the front end of each design phase for the communications system to determine if significant cost savings are available, but with the provision that the expected level of service and connectivity can be provided. There is not enough information available at this time to determine the possible range of savings, but the system would incur a recurring annual cost for effective lease of the fibers and be subject to future pricing increases when franchises expire or are renegotiated.

## 5.10 Video Detection Features

Some agencies are using video images to detect vehicles on approaches to traffic signals, as a means of replacing failure-prone loop detectors. Video images, in this application, may be fed back to a TMC for observation, but due to the angle of view and limited area being viewed (an approach to an intersection, in a fixed position) this image is not particularly useful in detecting incidents that occur in an intersection.

Some agencies have experimented with preset pan-tilt-zoom units on video detection systems to rotate cameras to the area of interest and then return them to their original view to continue their detection mode of operation. The problem with this approach is that the video detection schemes are so sensitive to their "background", that they never really get used to a changed background, the cameras never return to exactly the same view, and you lose all detection capability while the camera is panned to another location - all defeat the purpose of video detection and do not serve the notion of video monitoring very well.

Thus, if video detection is desired, those cameras should be assumed to be in a fixed position, fixed zoom and the images derived from them, if fed to a TMC, will provide limited value - but they can be used for this purpose.

Since video detection in itself is a localized issue tied to the local controller cabinet, video detection has no direct implications on the regional system design, with the possible exception of exporting a fixed view video feed as described above.

## 5.11 Preemption & Priority Features

Signal preemption, the ability to interrupt the normal operation of a traffic signal in favor of facilitating the passage of a special vehicle is in place in several intersections in the region. Preemption is allowed for emergency vehicles and for railroad activities located near a traffic signal.

The TAC discussions indicated that preemption is already present in several places and is likely to remain, and even be expanded over time. Recognizing this, the regional system is envisioned to be capable of notifying the system operator when a preemption event has occurred. This data will then be helpful in determining why congestion exists, perhaps otherwise unexpectedly, and help deal with identifying where a major emergency is occurring - translating into a need for signal adjustments.

The TAC discussions revealed that there is a desire to be able to distinguish between an emergency vehicle caused event and train caused event.

A lower form of disruption, that has not yet come to the Kansas City region but is worth consideration for future use is the concept of Apriority@. Popular in the transit industry, signal priority is the ability for a signal to recognize a special vehicle (usually a bus or light rail vehicle), and modify signal operations by extending an existing green display or shortening an existing red display to return to the green sooner than normal. This is different from preemption in that this concept does not demand immediately action, but is more subtle in how the signal reacts and tries to accommodate the special vehicle.

As in the preemption case, logging of the events would be desirable, by type of event. In both cases, if the local controller is capable of discerning direction preempted (or equating preemption on a phase basis), that would be desirable.

## 5.12 ITS Features

The traffic management system should offer the ability to link to and support roadway weather information systems (RWIS). Such systems typically consist of sensors that report temperature, humidity, wind speed, presence of moisture on the road surface and can be linked to other subsystems that can provide a level of weather prediction useful in evaluating maintenance and snow removal needs.

An ITS concept that was strongly embraced by the TAC was the concept of deployment of a series of Priority Corridors. These corridors could be the MARC corridors, or others, and typically have enhanced control and monitoring capability. Typical Priority Corridors around the country include features such as CCTV observation at critical intersections and congestion points, arterial style variable message signs mounted roadside or on traffic signal supports, and additional detection devices to monitor traffic speeds between intersections. The Priority Corridors actually utilize features described previously, but the concept differs in that a specific corridor will have a specific set of devices custom tailored for that specific location's design issues. The regional traffic management system should be capable of monitoring such Priority Corridors as a complete corridor, complete with traffic efficiency reporting capabilities.

The Priority Corridor concept responds very well in application to the need to support diversions parallel to freeways as well as primary corridors carrying longer distance commuter trips, such as the MARC corridors.

The concept of applying highway advisory radio (HAR) systems to the arterial street network was discussed and met with lukewarm reception. Problems associated with HAR that made the concept less attractive were distance limitations for broadcasts and that HAR system performance is sensitive to weather and terrain - both existing in the Kansas City area in such fashion that makes HAR difficult to successfully achieve its mission.

The concept of traffic adaptive controllers at intersections was discussed with the TAC in the November meeting, and it was also met with lukewarm response. The concept of traffic adaptive control is that the system is capable of monitoring traffic conditions from multiple detection devices (loops, video, etc.) and implement timing patterns in response to traffic conditions. The downside of traffic adaptive control is that it requires that all detection devices be in operating condition at all times for the control algorithms to effectively select the alternative timing patterns. Thus, a commitment to maintenance is greatly increased and must be very responsive when detection devices fail.

A second factor making traffic adaptive control a lower priority is the issue of repetitive traffic patterns. Such patterns, typically resulting from a high percentage of repeat commuter traffic, result in predictive traffic patterns. Such phenomena are responded to sufficiently with well planned traffic signal timing plans called into operation by time of day and day of week.

Other ITS features envisioned by the TAC included additional logical linkages that are a subset of the logical linkages previously discussed, such as dial-up information services, information kiosks, pager services and Internet linkages.

## 5.13 Flash Operation Features

The traffic management system should offer the ability, upon user demand, to configure selected intersections to go to a flash operation by time of day and day of week, adjustable from the TMC.

Some intersections are currently operated in that fashion and the flexibility of the system will allow continued application of this technique.

The system should also have the ability for the system operator to transmit a flash command to any connected intersection at any time to place the intersection into a flash mode. This mode shall remain active until it is replaced by a release command from the system operator or local technician at the site in the field.

## 5.14 High Water Event Features

Several high water sensors exist throughout the region. When water reaches a certain level, traffic operations are impacted due to flooding and closed road conditions. There was a desire expressed by the TAC to be able to monitor these devices for the purpose of predicting traffic impediments resulting from flooding. Logging would consist of location and time only.

## 5.15 System Elements Summary

If the TAC discussion of what the regional traffic management system elements was put in the form of a list of desired features, in order of importance as indicated by TAC members in a numerical exercise, that list would be the following:

### *Signal Monitoring & Data Exchange Features*

- Ability to monitor and control up to 5,000 field devices. Field devices may consist of traffic signals (up to 3,000), high water sensors (up to 1,000), arterial variable message signs and other traffic management devices (up to 1,000).
- Ability for any user agency to view signal timing data and monitor intersection operations for any signal connected to the regional system.

- Ability to log what local controller parameters are changed, and when. Distinguish between changes initiated remotely by a system user, by user ID, and via local keypad entry.
- The regional traffic management system shall utilize the NTCIP communications protocol between the traffic management center and field devices, and allow full uploading and downloading of entire controller data sets remotely.

### ***Communications System***

- Ability to operate in a mixed communications media environment, including copper cable, fiber optics and wireless technologies.
- Ability to provide adequate bandwidth and transmission integrity to support full motion video for up to 250 CCTV cameras.
- Flexibility to utilize existing cable TV or other (SCOUT) communications backbone structures as they are deployed.

### ***Detection Features***

- Ability to notify the system operator of a faulty loop detector channel, to the extent supported by the local cabinet and loop wiring configuration.
- Ability to support alternate forms of detection (RTMS, microwave, microloops, video imaging etc.), in gathering MOE information.
- Ability to modify signal timings on the fly in response to a faulty loop condition, upon operator approval.

### ***Security Features***

- Ability to provide a tiered user security system, where each user=s rights are identified by the system administrator:
  - Allow/disallow administrator selected users to perform data changes, download data, and view data.

- Allow/disallow administrator selected users to log into the system by time of day and day of week.
- Master data set administered at the system level, allowing multiple users access to the master data set. The master data set must match the local controllers, and thus a verification process shall be provided to check, verify and update as necessary. As local data changes are made at the controller, the system identifies the changes by comparison to the master data set, uploads, and updates the master data set and logs the change (see Data Exchange in above section, applicable to local data change logging).
- Ability to report when a local signal is back in operation from a power failure or flash condition, logging date and time of day.
- Ability to report a flash condition to the central operator, logging date and time of day, and depending on the ability of the local controller and cabinet wiring to support the following, distinguish between:
  - Police panel flash,
  - Cabinet switch flash,
  - Program flash, and
  - Conflict Monitor (MMU) initiated flash.
- Ability to report when a cabinet door is opened for more than a user-specified time period, and when the door has been re-closed for more than a user-specified time period.
- Ability to accommodate future linkages with external data portals, such as the freeway management system, other future traffic systems in the region/state and Internet with security from unauthorized data tampering or manipulation.

### ***Maintenance & Operations Features***

- Ability to support a GIS-based integrated traffic signal equipment inventory system.
- Ability to support an integrated Work Order system.

### ***Logical Linkages***

- Ability to export traffic signal timing data, views of intersection operations, and video images to the regional freeway management system operators. This export may be in a view only format until such time formalized agreements allow intervention by the SCOUT operators.
- Ability to import video images from the freeway management system closed circuit television system, based on user defined identification of camera feeds.
- Ability to support future data and video exports to Police, Fire, ambulance, and transit operators.
- Ability to monitor school crossing flasher sites to determine their operational status in terms of on/off.
- Ability to support a transit system linkage, capable of providing traveler information relative to transit operations.
- Ability to support Internet access into the system to observe traffic congestion information and video feeds from critical intersections. Any Internet connection must be safe from data manipulation and vandalism.
- Ability to support a media connection, capable of providing the same type of information as the Internet connection, but with limited access only to those approved by the traffic management authority - as opposed to the general public without limit.

### ***Measures of Effectiveness Features***

- Ability to graphically depict, in color, the main street greenband for user defined intersections along a corridor, while those intersections are operating in the coordinated mode.

- Ability to report volume and average speed for any user specified system detectors, including the ability to advance program detectors to collect and report to the central system for future retrieval and analysis of the data. Data should be in a spreadsheet compatible format (e.g. Excel).
- Ability to monitor and graphically report, in color, green and clearance allocations within a cycle at any user defined intersection, including the ability to advance program to collect and report to the central system for future retrieval and analysis of data.

### ***Video Monitoring Features***

- Ability to support and control full-motion color video images from up to 250 CCTV sites in the field, as an integrated module for the overall regional traffic management system.
- Ability to allow export of images and pan-tilt-zoom control to a participant agency based on level of allowed access.

### ***Preemption & Priority Features***

- Ability to log preemption events from connected intersections, to the extent supported by the local cabinet and controller assembly (phase affected or direction), on a user-defined basis, and transmit the logged event to the affected participant agency.
- Ability to discern between railroad preemption, emergency vehicle preemption and transit priority in logging and transmitting events.

### ***ITS Features***

- Ability to support Priority Corridors, and their associated features.
- Ability to support traffic adaptive control.
- Ability to link to and support RWIS systems.

- Ability to support Highway Advisory Radio.
- Ability to support additional traveler information services.

***Flash Operation***

- Ability to place user selected intersections in the flash mode by time of day, day of week schedule.
- Ability to place any connected intersection immediately into flash mode by remote command from the TMC, until released from the TMC.

***High Water Event Features***

- Ability to log high water events, to the extent that the available imported data source allows identification of location, time of day and event type.

## 6.0 Signal System Areas

### 6.1 INTRODUCTION

The purpose of this chapter is to identify potential control areas that have similar traffic characteristics and can operate in a similar fashion, thus making them logical intersections to link together and develop a common signal operational strategy. Development of the proposed control groups will be blind to jurisdictional boundaries, in support of the regional concept, and assuming full cooperation between participating agencies.

### 6.2 COUPLING INDEX

One of the main components in determining the potential control areas was by utilizing the coupling index for a particular segment of roadway. The coupling index is a dimensionless number computed as a ratio of two-way traffic volumes between the two signals on the roadway segment to the distance, in feet, between the signals. In equation form, the coupling index is:

$$I = V / L$$

Where:

I = Coupling Index

V = 2-way Total Traffic Volume/Peak Hour (vph)

L = Distance between Signals (ft.)

Typically, the two-way traffic volumes used are hourly volumes. When the coupling index is computed for the roadway being analyzed, a value of 0.5 or greater indicates that the signal should be coordinated during the time period from which the traffic volumes were used. For example, if the two-way traffic volume for a particular road is 3,500 vehicles during the morning peak hour and the two candidate signals on the road are one mile apart (5,280 feet), then the coupling index would equal 0.663 (rounded). Therefore, the coupling index suggests that these two signals be coordinated during the morning peak hour.

For this project, hourly volumes were not always available for every potential segment to be analyzed. Therefore, in order to maximize parity, twenty-four hour traffic volume data was used instead since this data was available for a majority of the segments being analyzed. In this case, the

0.5 coupling index value no longer applies since the calculation is no longer using hourly volumes. In order to determine the new coupling index value at which signals should be considered coordinated, the peak hour volume for a roadway was assumed to be 10% of the twenty-four hour traffic volume for the same roadway. Thus, a coupling index of 5 (0.5 divided by 10%) or greater represents a need for coordination in the analysis for this project. A further delineation was also used in this analysis which gives a higher coordination need to those segments where the coupling index is greater than 10.

## **6.3 COUPLING ANALYSIS PROCEDURE**

The coupling analysis procedure consisted of three steps:

### ***Segment Registration***

The first step in this process was to determine which sections of roadways were to be analyzed and to incorporate the selections into the already established ArcView GIS application. Segments were selected based on the type of roadway and traffic signal locations on the roadway. Various traffic volume data was superimposed over the roadway network to determine applicable traffic volumes for the particular segment being registered. Then, by utilizing a specially designed ArcView script (subroutine), the segments were traced out to determine their length, and then the appropriate traffic volume(s) assigned to the segment. This information was then stored in its own ArcView theme structure. Every segment was registered in this manner, until all roadway segments between traffic signals included in the study were acknowledged. Some segments did not have any corresponding traffic data that could be associated with it. In which case, the segment was still registered, but a zero value given for the traffic volume, which in turn results in a coupling index of zero. Other cases involved multiple applicable traffic volume data for a particular segment. In this case, an algorithm was used which registered the most recent traffic volume data, and/or averaged multiple data collections that came from the same year.

### ***Calculation of Coupling Index***

The next step in the procedure was to calculate the coupling indices for all of the registered segments. This calculation followed the equation presented above by dividing the traffic volume by the registered length (converted from miles to feet prior to calculation). The coupling index was stored along with the other registered data for every segment in the signal study area.

### ***Display of Results***

The coupling index was used to determine how to display the individual segments. Segments with a coupling index between 5 and 10 were considered to have a "high need for coordination," whereas segments with a coupling index 10 or above were considered to have the "highest need for coordination." Segments that did not have any associated traffic volume data were considered "inadequate data." Each type of segment was depicted as a different color. Figures 8 and 9, on the following pages, show the results of the coupling analysis.

## **6.4 CONTROL GROUP DETERMINATION**

Potential control groups were established by utilizing a plot of the study area showing coupling indices for the various segments and type of signals corresponding to each segment. Control groups representing peak hour conditions and off-peak conditions were determined.

The control groups established for off-peak hour operations generally were limited to segments that had a very high need for coordination as shown by the coupling index. These groups typically involve a few segments and are usually self-contained along a corridor. Peak hour control groups were expanded beyond the extent of the off-peak control groups to include segments that had a high need for coordination. These signal system groups may involve many segments over large areas, or may be confined to their off-peak control group depending on their location and the surrounding road network. Some control groups may include segments which do not have a need for coordination, but have been included for uniformity and functionality reasons.

The use of peak and off-peak control groups relates to the type of traffic volume data available and thus the coupling index calculated. The segments showing a high need for coordination, based on the criteria established for using 24-hour traffic volumes, will certainly have a high need for coordination in the peak hour since this is when traffic volumes are concentrated. Those segments that have a very high need will likely require coordination throughout the day in addition to the peak hour.

The potential peak hour control groups have been presented in Figure 8 along with information pertaining to coupling indices ("Need for Coordination"), type of signals, and geographic and political boundaries, although jurisdictions were not considered in the control group determinations.

Figure 9 is a similar plot showing the off-peak control groups for the MARC study area. These plots are not intended as the final determination of the control groups to be established. They basically represent the need for inter-jurisdictional control systems with operational flexibility based on the time of day and traffic conditions, and are subject to change as traffic increases or shifts to different roadways.

## **FIGURE 8 - PEAK HOUR CONTROL ZONES**

## **FIGURE 9 - OFF PEAK CONTROL ZONES**

## 7.0 Implementation Plan

### 7.1 INTRODUCTION

The purpose of this chapter is to identify and develop a staged regional plan for implementation of hardware, software, and communications infrastructure. The plan will rely on prioritized groups of corridors to be implemented as part of the overall system. The prioritization process primarily relied on the coupling index information associated with the various corridor sections. However, input from the Technical Advisory Committee (TAC) and Steering Committee was also used to modify and refine the corridor priorities.

### 7.2 CANDIDATE CORRIDOR SELECTION

The selection of candidate corridors was based on three sources:

1. The previously calculated coupling indices;
2. The length of the candidate corridor section; and,
3. Input from the Technical Advisory and Steering Committees.

The candidate selection process consisted of three steps:

#### *Selection By Coupling Index Data*

Sections of corridors, which could consist of the entire corridor, were first selected based on coupling index data for the group of segments representing the candidate section. The candidate section of a corridor would be determined by the continuity of high coupling index values ( $I \geq 5.0$ ). In other words, a candidate corridor section would consist of an interconnected group of segments with consistently high coupling index values, representing the highest need for coordination.

### ***Refining Candidates by Length of Corridor Section***

Since the ultimate goal of the regional system is to provide a better overall coordination for a large area, the length of the candidate corridor sections was important in determining the final candidates for prioritization. As a general guideline, candidates with lengths less than five miles were eliminated from the possible candidates. The remaining candidates were then deemed the Priority Corridors (also known as the Original Corridors).

### ***Technical Committee Input***

Upon review by the Technical Advisory and Steering Committee members, modifications were made to the candidate corridor sections. The local knowledge of the members provided insight in addition to the coupling index data. This resulted in some of the Original Corridors being lengthened as well as the addition of other corridor sections not selected by the process described above. The corridor sections suggested by the Committees are called Additional Corridors with respect to this study.

The Committees also voiced opinions regarding prioritization of the corridor sections near interchange ramps. These have also been included in the prioritization considerations and are named Interchange Ramps - First Priority (those directly involving traffic signals at the ramps or traffic signals very close to the ramps) and Interchange Ramps - Second Priority, which are extensions of the corridor sections to include traffic signals upstream or downstream of the interchange that showed need based on coupling index values.

## **7.3 PRIORITIZATION OF CORRIDORS**

Candidate corridors were located using the ArcView GIS project developed for this study. Each corridor is composed of segments which have their own associated description and traffic-related data. The information from the individual segments making up a corridor section were used to create a data set for the corridor section as a whole. The data associated with each candidate corridor section are listed below:

- Traffic signals (represented by their Signal ID) at the beginning and end of the section;
- Name of the corridor;

- Average coupling index value for the corridor section;
- Length of the corridor section in miles;
- Product of the average coupling index value and the length (for analytical purposes);
- Whether the corridor section was part of a MARC corridor;
- Number of traffic signals on the corridor section;
- Approximate number of jurisdictions/agencies the corridor section passes through;
- Type of communication media that is available along the section (if any);
- Total length of any communication media along the corridor section; and,
- Portion of the corridor section where inadequate data was present (in miles).

The data for each corridor section was then imported into a spreadsheet program. The groups of priority corridor sections will serve as the implementation guidelines:

Phase I:	<i>Original Corridors</i>
Phase IIA:	<i>Additional Corridors</i>
Phase IIB:	<i>Interchange Ramps - First Priority</i>
Phase IIC:	<i>Interchange Ramps - Second Priority</i>

Figures 10, 11 and 12 show the study region with the different priority groups depicted and the different types of traffic signals involved.

## **FIGURE 10 - PRIORITY CORRIDORS**

## **FIGURE 11 - PRIORITY CORRIDORS**

## **FIGURE 12 - PRIORITY CORRIDORS**

## 7.4 FIELD HARDWARE IMPLEMENTATION COSTS

In order to estimate the implementation costs, the existing network of roads and traffic signal interconnect means were considered.

The type of traffic signal controller currently in place was important since the regional traffic management system will be based on Type 170 or 2070 traffic signal controllers. This is an attempt to provide a consistent, non-manufacturer specific controller unit capable of the robust job of controlling an intersection plus handle NTCIP protocol communications. The 2070 family of controllers offers additional expansion capabilities, including on-board video cards and allows easy retrofit into existing Type 170 and NEMA cabinets (Type 2070N), and is thus the preferred controller platform. The 2070 controller offers the additional ability to control a variety of other devices such as CCTV cameras, detectors and ramp metering in the future. This permits future devices being controlled with the same hardware.

It should be noted that the implementation of regional arterial corridors superimposed on existing grid signal systems will complicate the operation of the rest of the grid. The agency responsible for the grid system intersecting the MARC corridor will have the following options:

- Continue to run the rest of the grid system on another timing pattern. This would result in no progression for vehicles moving across the MARC corridor on an intersecting street, or
- Match the MARC corridor timing plan. This would be done by using the same cycle length as is used on the MARC corridor and establishing cross street corridor offsets relative to the Operation Green Light signals. This could be done by WWV time sync between the regional master and the local master or with the local controllers using time based coordination with WWV packs at each site.

The Operation Green Light regional master should have sufficient capacity to permit the local agencies to control signals which are not on the priority corridors. The local agency would need to purchase the necessary 2070 controllers and establish communication between the master and the intersection. The advantage of such an arrangement is that each of the numerous agency participants in Operation Green Light who do not current have a system master, or wish to replace their master in the near future could avoid the central hardware and software cost of a new ATMS.

Existing traffic signal interconnect was relevant since it could be reused, at least for the short term until such time the data demands of video images require fiber or other broadband media. In the short term, as a means of quick interconnection in cases where the communications system funding is limited and no other existing interconnect is available, the regional traffic management system will require multiple master spread spectrum radios and repeater radios located throughout the region. If terrain interferes with communications, additional radio repeaters may be necessary. A limited amount of such extra repeaters has been accounted for in the project estimates.

The masters would be located in centralized areas in order to communicate with a maximum number of traffic signals via repeater spread spectrum radios. The repeater radios would be located within line-of-sight of sections of traffic signals equipped with remote spread spectrum radios. The repeater would also operate within line-of-sight of one traffic signal equipped with a remote radio that is currently using existing interconnect to another traffic signal or signals. This way, the pre-existing interconnect available on some of the Priority Corridor sections can be reused by only providing one remote radio for the interconnected group.

It is estimated that the regional system would need approximately 470 spread spectrum radios. Also, each traffic signal will need a Type 170, 2070 or 2070N controller configured with a consistent software package for all such system locations. Therefore, the equipment and functionality of each Priority Corridor section was analyzed to determine an overall cost estimate for implementing Phase I and Phase II.

In Phase I and II of implementation, it is estimated that approximately 204 NEMA controllers and cabinets along with 97 controllers and cabinets of unknown type will be replaced by either Type 170 or Type 2070 controllers and cabinets.

470 spread spectrum radio sets (10 masters, 51 repeaters, and 409 remotes) are estimated to be required for the purpose of signal communication in addition to the already existing communication.

These radio requirements are estimates for planning and budgetary purposes only, since the actual number will depend on master and repeater locations and line of sight. This cannot be determined until the design phase.

As the communications plan is funded and deployed, which can be done completely independent, but in parallel with the traffic management system hardware and software, the wireless media will be transitioned out in some areas and made available for reuse in other areas requiring connection to the system - but without existing interconnect.

The breakdown of infrastructure requirements by control groups (Original Corridors, Additional Corridors, and Interchange Ramps) for the different phases are shown in Table 1. Table 2 shows the infrastructure requirements for the remaining study signals.

For the purpose of controller and cabinet cost estimation, various local and regional vendors of Type 170 and 2070 controllers and cabinets were contacted. Based on discussions with them, it is estimated that the cost of removing an existing controller and cabinet and replacing it with a Type 170 controller and cabinet will be approximately \$ 10,000 each. Replacing with a Type 2070 controller and cabinet will be approximately \$12,000 each. This estimated cost is complete with hardware, software and labor costs included.

It should be noted that approximately 1/3 of the Unified Government and 2/3 of the Kansas City, Missouri cabinets are pole-mounted. These locations would require the pole-mounted cabinets be replaced with base-mounted cabinets. The replacement cost for these locations is estimated to be \$1,000 more than the previously mentioned estimates. For the purpose of this planning level cost estimate, it was assumed that approximately half of the cabinet replacements would require new base mounted pads and conduit, therefore a cost estimate of \$10,500 for Type 170 and \$12,500 for 2070 per location was used.

Although there are different hardware and software configurations for the 2070 controller, the most basic version will be more than adequate for controlling an intersection. Additional requirements such as supporting video, providing NEMA connectors to mate to adequate sized existing NEMA cabinets, detection ramp metering, etc. will be considered in the design phase. Although based on the need for intersection control only, the previously mentioned cost estimates should be adequate to provide for some additional features.

For the purpose of estimating communication cost using spread spectrum radios, a vendor of spread spectrum radios serving the Kansas City area was contacted for pricing data. It is estimated that the cost of a spread spectrum radio, including its installation will be approximately \$ 3,000 per site. Radio assumptions included one remote for each intersection without existing communication, plus one repeater per corridor.

It should be noted that in the near term, those Priority Corridors which include signals that are already a part of a modern and functional coordinated system (e.g. Overland Park) will likely continue to be timed and monitored by their existing system with a timing pattern to match the Priority Corridor timing pattern. Time sync can be provided either by master to master communication or WWV time sync.



**Table 1. Infrastructure Requirements - Priority Corridors**

Description	Number of Signals	170 Controllers	NEMA Controllers	Unknown Controllers	Spread Spectrum Radios		
					Remotes	Repeaters	Masters
<b>PHASE I</b>							
<b>Original Corridors:</b>	<b>316</b>	<b>179</b>	<b>73</b>	<b>64</b>	<b>228</b>	<b>15</b>	<b>6</b>
Missouri Portion	178	75	40	63	164	8	3
Kansas Portion	138	104	33	1	64	7	3
<b>PHASE IIA</b>							
<b>Additional Corridors:</b>	<b>117</b>	<b>25</b>	<b>73</b>	<b>19</b>	<b>80</b>	<b>7</b>	<b>2</b>
Missouri Portion	90	13	59	18	65	6	2
Kansas Portion	27	12	14	1	15	1	0
<b>PHASE IIB</b>							
<b>Interchange Ramps</b>	<b>94</b>	<b>40</b>	<b>44</b>	<b>10</b>	<b>58</b>	<b>29</b>	<b>2</b>
Missouri Portion	62	8	44	10	49	20	2
Kansas Portion	32	32	0	0	9	9	0
<b>PHASE IIC</b>							
<b>Interchange Ramps</b>	<b>56</b>	<b>38</b>	<b>14</b>	<b>4</b>	<b>43</b>	<b>-</b>	<b>-</b>
Missouri Portion	36	21	11	4	34	-	-
Kansas Portion	20	17	3	0	9	-	-
<b>Total:</b>	<b>583</b>	<b>282</b>	<b>204</b>	<b>97</b>	<b>409</b>	<b>51</b>	<b>10</b>
<b>Missouri Portion</b>	<b>366</b>	<b>117</b>	<b>154</b>	<b>95</b>	<b>312</b>	<b>34</b>	<b>7</b>
<b>Kansas Portion</b>	<b>217</b>	<b>165</b>	<b>50</b>	<b>2</b>	<b>97</b>	<b>17</b>	<b>3</b>



**Table 2. Infrastructure Requirements - Remaining Study Signals**

Description	Number of Signals	170 Controllers	NEMA Controllers	Unknown Controllers	Spread Spectrum Radio*		
					Remotes	Repeaters	Masters
<b>Remaining Study Signals on MARC Corridors</b>	<b>497</b>	<b>186</b>	<b>205</b>	<b>106</b>	<b>348</b>	<b>43</b>	<b>1</b>
Missouri Portion	318	108	106	104	265	28	0
Kansas Portion	179	78	99	2	83	15	1
<b>Remaining Study Signals not on MARC Corridors</b>	<b>420</b>	<b>97</b>	<b>135</b>	<b>188</b>	<b>295</b>	<b>37</b>	<b>1</b>
Missouri Portion	319	88	43	188	225	25	1
Kansas Portion	101	9	92	0	70	12	0
<b>Total</b>	<b>917</b>	<b>283</b>	<b>340</b>	<b>294</b>	<b>643</b>	<b>80</b>	<b>2</b>
Missouri Portion	637	196	149	292	490	53	1
Kansas Portion	280	87	191	2	153	27	1

\* Assumes total radio requirements would be approximately the same proportion as total radio requirements for the signals on the Priority Corridors (see Table 1), except for the master radios, which were taken as a 20% increase from the Priority Corridor requirements due to regional dispersion for the Priority Corridors

In order to estimate the traffic signal control hardware and communications cost for implementation of Phase I and II, two possibilities were considered:

- **Not replacing “unknown” controllers** - This involves replacing the 204 NEMA controllers and cabinets with Type 170 or 2070 controllers and cabinets. This option assumes that the “unknown” controller types are Type 170 and do not require replacement of the hardware. Also, the cost of installing 470 spread spectrum radio sets was estimated. Table 3 presents the cost summary. It is estimated that approximately \$3,450,000 will be needed to replace the existing NEMA controllers and cabinets with Type 170 controllers and cabinets and to install spread spectrum radio communication. The cost of replacing the existing NEMA controllers and cabinets with Type 2070 controllers and cabinets and to install spread spectrum radio communication will be approximately \$3,858,000.
- **Replacing “unknown” controllers** - This involves replacing the 204 NEMA controllers and cabinets as well as 97 controllers and cabinets of unknown type with either Type 170 controllers and cabinets or Type 2070 controllers and cabinets. Also, the cost of installing 470 spread spectrum radio sets was estimated. Table 4 presents the cost summary. It is estimated that approximately \$4,420,000 will be needed to replace the existing NEMA and unknown controllers and cabinets with Type 170 controllers and cabinets and to install spread spectrum radio communication. The cost of replacing the existing NEMA and unknown controllers and cabinets with Type 2070 controllers and cabinets and to install spread spectrum radio communication will be approximately \$5,022,000.

For system estimating purposes it was assumed that those unknown controller types would be replaced, because they were predominately older controllers, apparently for which records of controller type were unavailable.

No costs were assumed for intersection geometric modifications. For this reason it was not assumed that wheelchair ramps, modified pedestrian push buttons or other modifications to gain ADA compliance would be provided as a part of this project.



**Table 3. Cost Estimates - Controllers, Cabinets & Communications - Priority Corridors & Remaining Study Signals**  
(Not Including The Cost of Replacing Unknown Controller Types)

Description	Unit Cost (Dollars)	Original Corridors		Additional Corridors		Interchange Ramps First Priority		Interchange Ramps Second Priority		Total Cost Priority Corridors (Dollars)	Remaining Study Signals on MARC Corridors		Remaining Study Signals not on MARC Corridors		Total Cost Remaining Study Signals (Dollars)	Total Cost Entire Regional System (Dollars)
		Quantity	Cost (Dollars)	Quantity	Cost (Dollars)	Quantity	Cost (Dollars)	Quantity	Cost (Dollars)		Quantity	Cost (Dollars)	Quantity	Cost (Dollars)		
<b>170 Controller &amp; Cabinet &amp; Installation</b>		73	\$ 766,500	73	\$ 766,500	44	\$ 462,000	14	\$ 147,000	\$ 2,142,000	205	\$ 2,152,500	135	\$ 1,417,500	\$ 3,570,000	\$ 5,712,000
Missouri Portion		40	\$ 420,000	59	\$ 619,500	44	\$ 462,000	11	\$ 115,500	\$ 1,617,000	106	\$ 1,113,000	43	\$ 451,500	\$ 1,564,500	\$ 3,181,500
Kansas Portion	\$ 10,500	33	\$ 346,500	14	\$ 147,000	0	\$ 0	3	\$ 31,500	\$ 525,000	99	\$ 1,039,500	92	\$ 966,000	\$ 2,005,500	\$ 2,530,500
<b>2070 Controller &amp; Cabinet &amp; Installation</b>		73	\$ 912,500	73	\$ 912,500	44	\$ 550,000	14	\$ 175,000	\$ 2,550,000	205	\$ 2,562,500	135	\$ 1,687,500	\$ 4,250,000	\$ 6,800,000
Missouri Portion		40	\$ 500,000	59	\$ 737,500	44	\$ 550,000	11	\$ 137,500	\$ 1,925,000	106	\$ 1,325,000	43	\$ 537,500	\$ 1,862,500	\$ 3,787,500
Kansas Portion	\$ 12,500	33	\$ 412,500	14	\$ 175,000	0	\$ 0	3	\$ 37,500	\$ 625,000	99	\$ 1,237,500	92	\$ 1,150,000	\$ 2,387,500	\$ 3,012,500
<b>Spread Spectrum Radio &amp; Installation</b>		249	\$ 747,000	89	\$ 267,000	89	\$ 267,000	43	\$ 129,000	\$ 1,410,000	392	\$ 1,176,000	333	\$ 999,000	\$ 2,175,000	\$ 3,585,000
Missouri Portion		175	\$ 525,000	73	\$ 219,000	71	\$ 213,000	34	\$ 102,000	\$ 1,059,000	293	\$ 879,000	251	\$ 753,000	\$ 1,632,000	\$ 2,691,000
Kansas Portion	\$ 3,000	74	\$ 222,000	16	\$ 48,000	18	\$ 54,000	9	\$ 27,000	\$ 351,000	99	\$ 297,000	82	\$ 246,000	\$ 543,000	\$ 894,000
<b>Option 1 - 170 Controller &amp; Cabinet with Spread Spectrum Radio</b>			\$ 1,513,500		\$ 1,033,500		\$ 729,000		\$ 276,000	\$ 3,552,000		\$ 3,328,500		\$ 2,416,500	\$ 5,745,000	\$ 9,297,000
Missouri Portion			\$ 945,000		\$ 838,500		\$ 675,000		\$ 217,500	\$ 2,676,000		\$ 1,992,000		\$ 1,204,500	\$ 3,196,500	\$ 5,872,500
Kansas Portion			\$ 568,500		\$ 195,000		\$ 54,000		\$ 58,500	\$ 876,000		\$ 1,336,500		\$ 1,212,000	\$ 2,548,500	\$ 3,424,500
<b>Option 2 - 2070 Controller &amp; Cabinet with Spread Spectrum Radio</b>			\$ 1,659,500		\$ 1,179,500		\$ 817,000		\$ 304,000	\$ 3,960,000		\$ 3,738,500		\$ 2,686,500	\$ 6,425,000	\$ 10,385,000
Missouri Portion			\$ 1,025,000		\$ 956,500		\$ 763,000		\$ 239,500	\$ 2,984,000		\$ 2,204,000		\$ 1,290,500	\$ 3,494,500	\$ 6,478,500
Kansas Portion			\$ 634,500		\$ 223,000		\$ 54,000		\$ 64,500	\$ 976,000		\$ 1,534,500		\$ 1,396,000	\$ 2,930,500	\$ 3,906,500

*Note: These estimates do not take into consideration the possible cost of replacing controllers and cabinets at those signal location where controller and cabinet information is not available*



**Table 4. Cost Estimates - Controllers, Cabinets & Communications - Priority Corridors & Remaining Study Signals**  
(Including The Cost of Replacing Unknown Controller Types)

Description	Unit Cost (Dollars)	Original Corridors		Additional Corridors		Interchange Ramps First Priority		Interchange Ramps Second Priority		Total Cost Priority Corridors (Dollars)	Remaining Study Signals on MARC Corridors		Remaining Study Signals not on MARC Corridors		Total Cost Remaining Study Signals (Dollars)	Total Cost Entire Regional System (Dollars)
		Quantity	Cost (Dollars)	Quantity	Cost (Dollars)	Quantity	Cost (Dollars)	Quantity	Cost (Dollars)		Quantity	Cost (Dollars)	Quantity	Cost (Dollars)		
<b>170 Controller &amp; Cabinet &amp; Installation</b>		137	1,438,500	92	966,000	54	567,000	18	189,000	3,160,500	311	3,265,500	323	3,391,500	\$ 6,657,000	\$ 9,817,500
Missouri Portion		103	1,081,500	77	808,500	54	567,000	15	157,500	2,614,500	210	2,205,000	231	2,425,500	\$ 4,630,500	\$ 7,245,000
Kansas Portion	\$10,500	34	357,000	15	157,500	0	0	3	31,500	546,000	101	1,060,500	92	966,000	\$ 2,026,500	\$ 2,572,500
<b>2070 Controller &amp; Cabinet &amp; Installation</b>		137	1,712,500	92	1,150,000	54	675,000	18	225,000	3,762,500	311	3,887,500	323	4,037,500	\$ 7,925,000	\$ 11,687,500
Missouri Portion		103	1,287,500	77	962,500	54	675,000	15	187,500	3,112,500	210	2,625,000	231	2,887,500	\$ 5,512,500	\$ 8,625,000
Kansas Portion	\$12,500	34	425,000	15	187,500	0	0	3	37,500	650,000	101	1,262,500	92	1,150,000	\$ 2,412,500	\$ 3,062,500
<b>Spread Spectrum Radio &amp; Installation</b>		249	747,000	89	267,000	89	267,000	43	129,000	1,410,000	392	1,176,000	333	999,000	\$ 2,175,000	\$ 3,585,000
Missouri Portion		175	525,000	73	219,000	71	213,000	34	102,000	1,059,000	293	879,000	251	753,000	\$ 1,632,000	\$ 2,691,000
Kansas Portion	\$3,000	74	222,000	16	48,000	18	54,000	9	27,000	351,000	99	297,000	82	246,000	\$ 543,000	\$ 894,000
<b>Option 1 - 170 Controller &amp; Cabinet with Spread Spectrum Radio</b>			2,185,500		1,233,000		834,000		318,000	4,570,500		4,441,500		4,390,500	\$ 8,832,000	\$ 13,402,500
Missouri Portion			1,606,500		1,027,500		780,000		259,500	3,673,500		3,084,000		3,178,500	\$ 6,262,500	\$ 9,936,000
Kansas Portion			579,000		205,500		54,000		58,500	897,000		1,357,500		1,212,000	\$ 2,569,500	\$ 3,466,500
<b>Option 2 - 2070 Controller &amp; Cabinet with Spread Spectrum Radio</b>			2,459,500		1,417,000		942,000		354,000	5,172,500		5,063,500		5,036,500	\$ 10,100,000	\$ 15,272,500
Missouri Portion			1,812,500		1,181,500		888,000		289,500	4,171,500		3,504,000		3,640,500	\$ 7,144,500	\$ 11,316,000
Kansas Portion			647,000		235,500		54,000		64,500	1,001,000		1,559,500		1,396,000	\$ 2,955,500	\$ 3,956,500

*Note: These estimates include the cost of replacing controllers and cabinets at those signal locations where controller and cabinet information is not available based on the assumption that the signal locations have other than 170 controllers and cabinets.*

## **7.5 SYSTEM IMPLEMENTATION COSTS**

In addition to the field hardware costs, the cost for the central hardware and software was estimated. This cost was also estimated by the previously described phases to permit the design and bid packages to be assembled in various manners depending on available funding. Similarly, design costs and system timing costs were estimated by phase.

In the event an agency wants to communicate to a signal that is not a part of the regional system for operational purposes, but it is desired for monitoring the intersection, the same cost data for the radio connection would be useful, assuming any variations required as a result of the physical location and radio accessibility of the site is accounted for.

Because MARC does not typically bid and administer design contracts, a cost was also included for system management. It is assumed that if staff resources are not available for construction administration, a system manager would be required. The total cost estimates by phase, for the traffic signal control equipment and fiber optic communications system discussed in Section 5.9, are included in Table 5.

## **7.6 RECOMMENDED IMPLEMENTATION METHOD**

Deployment of Advanced Traffic Management Systems is not suited for traditional design and low bid implementation. This is because it is a rapidly changing technology and one which is not consistently implemented by all system providers. There are several disadvantages to the traditional bidding process in deployment of a system such as Operation Green Light as follows:

- If a detailed design were done, it likely would favor some systems which use a technology similar to the design and may penalize a more current or innovative design which does not meet the detailed design methods.
- A detailed design “locks in” the technology at the time of design.
- The need to change the system configuration during implementation may result in requests for change order since it is unlikely that any system will exactly meet the design, especially if the design is sufficiently detailed to provide the desired system.



**Table 5. Cost Estimate by Phase - Priority Corridors & Remaining Study Signals**

PHASE	Description	Total Number of Intersections	Design Cost	Central Hardware & Software	Controller & Cabinet (Installed)*	Radio Cost (Installed)	Signal Timing	System Management	Contingencies	Total Cost
I	Original Corridors	316	\$600,000	\$1,500,000	\$1,712,500	\$747,000	\$300,000	\$300,000	\$515,950	\$5,675,450
	Missouri Portion	178		\$1,110,000	\$1,287,500	\$525,000	\$168,000			\$3,090,500
	Kansas Portion Shared	138	\$600,000	\$390,000	\$425,000	\$222,000	\$132,000	\$300,000	\$515,950	\$1,415,950
IIA	Additional Corridors	117	\$100,000	\$100,000	\$1,150,000	\$267,000	\$100,000	\$50,000	\$176,700	\$1,943,700
	Missouri Portion	90		\$83,000	\$962,500	\$219,000	\$77,000			\$1,341,500
	Kansas Portion Shared	27	\$100,000	\$17,000	\$187,500	\$48,000	\$23,000	\$50,000	\$176,700	\$326,700
IIB	1 <sup>st</sup> Priority Interchange Ramps	94	\$100,000	\$100,000	\$675,000	\$267,000	\$100,000	\$50,000	\$129,200	\$1,421,200
	Missouri Portion	62		\$94,000	\$675,000	\$213,000	\$66,000			\$1,048,000
	Kansas Portion Shared	32	\$100,000	\$6,000	\$0	\$54,000	\$34,000	\$50,000	\$129,200	\$279,200
IIC	2 <sup>nd</sup> Priority Interchange Ramps	56	\$50,000	\$50,000	\$225,000	\$129,000	\$50,000	\$25,000	\$52,900	\$581,900
	Missouri Portion	36		\$41,000	\$187,500	\$102,000	\$32,000			\$362,500
	Kansas Portion Shared	20	\$50,000	\$9,000	\$37,500	\$27,000	\$18,000	\$25,000	\$52,900	\$127,900
III	Regional TOC		\$500,000	\$5,000,000				\$100,000	\$500,000	\$6,100,000
IV	Communications System		\$2,250,000	\$22,500,000				\$750,000	\$750,000	\$26,250,000
V	Remaining Study Signals on MARC Corridors	497	\$500,000	\$500,000	\$3,887,500	\$1,176,000	\$500,000	\$250,000	\$681,350	\$7,494,850
	Missouri Portion	318		\$345,000	\$2,625,000	\$879,000	\$320,000			\$4,169,000
	Kansas Portion Shared	179	\$500,000	\$155,000	\$1,262,500	\$297,000	\$180,000	\$250,000	\$681,350	\$1,894,500
VI	Remaining Study Signals not on MARC Corridors	420	\$400,000	\$400,000	\$4,037,500	\$999,000	\$400,000	\$200,000	\$643,650	\$7,080,150
	Missouri Portion	319		\$288,000	\$2,887,500	\$753,000	\$304,000			\$4,232,500
	Kansas Portion Shared	101	\$400,000	\$112,000	\$1,150,000	\$246,000	\$96,000	\$200,000	\$643,650	\$1,243,650

\* Includes new 2070 controller and cabinet at all locations with other than type 170 controller.

A better method, and one which has been successfully used by the project team in several locations is the use of a functional specification where the various potential system providers would be required to respond to the functional spec. At a minimum they would certify that their system meets the functional specification as presented, however they would be encouraged to meet the intent of the specification using their own innovation and creativity. This results in the best system at the lowest cost. There are several methods after "short-listing" potential providers based on their proposal (i.e., their response to the functional specifications).

One method that has been successfully used is to evaluate and rate the proposals by an evaluation team. After the rating is done, a second envelope with the cost of each short-listed system is opened. The cost is included in the evaluation process in a pre-determined manner. For example, if it is determined that system cost is to be 40% of the evaluation process, the lowest quote of the short-listed systems is given 40 points out of a total of 100 points for cost. The remaining short-listed systems receive points in inverse proportion to their system cost when compared to the least cost short-listed system.

## **7.7 OPERATING & MAINTENANCE COSTS**

As the various portions of the system become operational, the operating entities must consider the cost of continued operations and maintenance. The Texas Transportation Institute's Ginger Daniels and co-author Tim Starr conducted a study in 1999 that identified some of these costs, as shown in the following table. If deployment is several years away, the costs indicated in the table should be tempered with a factor for inflation. The complete research report results are contained in Appendix G, providing further detail.

Costs include the cost of labor for periodic and trouble call maintenance, maintenance contract costs, cost of repair equipment, transportation and personnel benefits.

The operating cost of a traffic management center is a much more complicated issues that is a product of the type of facility the center is housed in (leased vs. owned, square footage, etc.), number of employees, and how the multi-agency approach divides the cost sharing. As the control center develops from a concept to a design element, a detailed economic analysis of the equipment and labor costs should be conducted and separate the pro rata share of services emanating from, and thus the cost borne by, the traffic control center versus services that may be provided by employees of a specific agency that is simply using the center as a base of operation.

**Table 6. Annual Operations & Maintenance Cost**

Device	Annual O & M Cost
Control Center <sup>1</sup>	\$10,000 - \$50,000
Fiber Optic (per mile)	\$800
Spread Spectrum Radio (per hop)	\$300
Detector Loop (each)	\$200 - \$300
Signal Controller & Cabinet (each)	\$2,500 - \$4,000
CCTV Camera (each)	\$500 - \$1,800
Signal Timing (per signal)	\$500 - \$1,000
Variable Message Sign	\$3,000 - \$4,000

Source: Guidelines for Funding Operations and Maintenance of Intelligent Transportation Systems/Advanced Traffic Management Systems, Ginger Daniels and Tim Starr, Texas Transportation Institute, 1999

**Notes:** <sup>1</sup> Does not include personnel costs for staffing at TMC.

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## 8.0 Air Quality Implications

### 8.1 INTRODUCTION

This chapter discusses the potential air quality benefits of Operation Green Light. The object of this evaluation is to predict the reduction in automobile emissions including Carbon Monoxide (CO), Hydrocarbons (HC), and Oxides of Nitrogen (NO<sub>x</sub>). The first section describes the Congestion Mitigation and Air Quality Improvement (CMAQ) program, the second section describes the MARC program and the need for evaluation of air quality. Then, the following section presents the methodology for estimation of automobile emissions reduction.

### 8.2 THE CMAQ PROGRAM

The United States Congress initiated the Congestion Mitigation and Air Quality Improvement (CMAQ) program to fund transportation projects or programs that will contribute to attainment or maintenance of the National Ambient Air Quality Standards (NAAQS) for Ozone and CO. The recently enacted TEA-21 legislation also allows CMAQ funding to be expanded in particulate matter (PM) non-attainment and maintenance areas.

CMAQ has authorized \$1,345,415,000 nationally for the current fiscal year. It should be noted that CMAQ is not the only source of funds to reduce congestion and improve air quality. Funds under the Surface Transportation Program (STP) and the Federal Transit Administration (FTA) capital assistance programs may be used for this purpose as well.

The CMAQ funds are apportioned annually according to factors largely based on air quality need, which are calculated in the following manner: the population of each area in a state (based on Census bureau data by county), that, at the time of apportionment, is a non-attainment or maintenance area for ozone and/or CO and meets the classification contained in the Clean Air Act (CAA), is multiplied by the apportionment factor presented in Table 7. Two key changes are included in the apportionment factors under TEA-21. Areas that are designated and classified as submarginal and maintenance areas for Ozone are now explicitly included in the apportionment formula, and there are new weighting factors for CO non-attainment areas. Furthermore, each state is guaranteed at least  $\frac{1}{2}$  of 1 percent of each year's CMAQ authorized funding regardless of whether the State has any non-attainment or maintenance areas.

**Table 7. TEA-21 CMAQ Apportionment Factors**

<b>Pollutant</b>	<b>Classification At The Time Of Annual Apportionment</b>	<b>Weighting Factor</b>
Ozone or CO	Maintenance	0.8
	Submarginal	0.8
	Marginal	1.0
	Moderate	1.1
	Serious	1.2
	Severe	1.3
	Ozone	Extreme
CO	Non-attainment	1.0
Ozone and CO	Ozone non-attainment or maintenance and CO maintenance	1.1 x Ozone factor
	Ozone non-attainment or maintenance and CO non-attainment	1.2 x Ozone factor
All States - minimum apportionment	2 of 1 percent total annual apportionment of CMAQ funds	N/A

*Source: CMAQ Program Under the TEA-21 Program Guidance, April 1999*

MARC, being a maintenance area for ozone, is eligible for CMAQ funding. A non-attainment area by definition is an area where the air quality does not comply with the NAAQS set by Environmental Protection Agency (EPA). A maintenance area by definition is an area where the air quality complies with NAAQS but has been a non-attainment area in the past. The CMAQ program was started by Congress to fund transportation projects or programs that will contribute to attainment of the NAAQS. The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) strongly encourage state and local governments to use CMAQ funds for

transportation projects that result in reduction of automobile emissions and attainment of NAAQS. To obtain CMAQ funding, the transportation projects have to demonstrate that a tangible reduction in emissions could be achieved by their implementation. Therefore, Operation Green Light must demonstrate automobile emissions reduction in order to obtain CMAQ funding.

### **8.3 OPERATION GREEN LIGHT PROGRAM (PHASE 1)**

The Phase 1 Application of the Operation Green Light program includes the 583 traffic signals represented in Table 1 of Chapter 7 (where Phase 1 consists of Phases I, IIA, IIB, and IIC). These corridors, shown in Figures 10, 11 and 12 in Chapter 7, receive approximately 8.0 percent of the total vehicle-miles of travel (VMT) in the Kansas City region. They are the highest priority based on the process discussed in Chapter 7. Phase V of the Implementation Plan contains those signals on the MARC corridors which were not included in the Phase 1 application. Phase VI of the Implementation Plan contains the remaining signals which were part of this study which were not on the original MARC study corridors. This chapter presents an analysis of the air quality impacts estimated to result from deployment of Phase 1 of Operation Green Light ( Phases I, IIA, IIB, and IIC of the Implementation Plan) as well as the impacts resulting from Phase V and VI of the Implementation Plan.

### **8.4 TRAVEL TIME STUDY**

In order to determine the average speed of the arterials that are part of Operation Green Light, travel time studies were conducted on selected corridors. These travel time corridors are shown in Figure 13. Travel time data was collected using a global positioning system (GPS). A vehicle with a GPS device interfaced with a laptop computer with appropriate travel time software was driven along the corridors. Six runs in each direction in three time periods (AM peak, off-peak, and PM peak) were conducted. The AM peak hours sampled were 6:30 AM to 9 AM. The PM peak hours were 3:30 PM to 6 PM. The off-peak hours represented all other times of the day. The travel time data for these runs is shown in the Appendix.

The average speed for these corridors was determined by using a weighted average of the speed in the AM peak, off-peak and PM peak hours. This was done by estimating the percent of the traffic volume in each of these three periods. Generally, approximately eight percent of the 24-hour volume occurs during the AM peak hour, and nine percent of the 24-hour volume occurs during PM peak hour. Using these numbers it was estimated that 19 percent of the 24-hour volume occurred.

# FIGURE 13 – TRAVEL TIME CORRIDORS



**Table 8. Travel Time Corridor Data**

	Corridor Number										
	1	2	3	4	5	6	7	8	9	10	11
<b>AM Speed (mph)</b>	29.75	26.25	35.05	28	34.35	29.7	20	27.75	36.8	31.2	28.25
<b>Off Peak Speed (mph)</b>	30.15	25.75	36.6	29.45	33.6	33.9	21.35	29.25	28.6	32.05	33.8
<b>PM Speed (mph)</b>	27	24.3	30.75	24.25	31.3	30.9	18.5	28.95	30.1	28.35	30.15
<b>AM Volume*</b>	3842	3034	7301	3617	6293	5137	2192	4057	2796	2216	6007
<b>Off Peak Volume*</b>	12131	9580	23054	11422	19873	16221	6923	12812	8830	6998	18969
<b>PM Volume*</b>	4246	3353	8069	3998	6956	5677	2423	4484	3090	2449	6639
<b>ADT</b>	20219	15966	38424	19037	33122	27035	11539	21353	14716	11663	31615
<b>Length (mi)</b>	8.9	8.2	9.25	15.1	9.9	11.6	5.2	8.2	7	8.7	5.7
<b>VMT</b>	179949	130921	355422	287459	327908	313606	60003	175095	103012	101468	180206
<b>Weighted Average Speed</b>	29.41	25.54	35.08	28.08	33.26	32.47	20.50	28.90	30.47	31.11	31.98

\* Calculated based on the assumption of 19% of ADT for AM period (6:30-9), 60% of ADT for Off Period (9a-3:30p, 6p-6:30a), and 21% of ADT for PM Period (3:30-6)

during the AM period of 6:30 AM to 9 AM. Furthermore it was assumed that 21 percent of the 24-hour volume occurred during PM Peak period of 3:30 PM to 6 PM. The remaining 60 percent of the volume represents the off-peak period.

Table 8 shows the average daily speed on each of the 11 corridors determined by this process.

## 8.5 REDUCTION IN EMISSIONS

Currently, there are many computer modeling software packages available (e.g., MOBILE, EMFAC, Urban Airshed Model (UAM), SAI program, SANDAG program, TCM Analyst, etc.) for estimation of automobile emissions reduction. Various state and local governments rely on various computer models. However, EPA approves and requires use of the MOBILE model for estimation of automobile emissions reduction.

For the purpose of this study, the MOBILE 5a model will be used. This model calculates automobile emissions reduction as a function of average speed and vehicle miles of travel (VMT). The model produces automobile emission factors for Hydrocarbons, Carbon Monoxide, and Oxides of Nitrogen based upon the vehicle fleet information, vehicle fuel information, vehicle operating conditions, temperature data, and vehicle inspection data specified by the user. The automobile emission factors for various emissions and speeds were obtained by MARC using the MOBILE 5a model. Based on these automobile emission factors, the reduction in automobile emissions (for CO, HC, and NO<sub>x</sub>) were calculated in the following manner:

$$E_t = [F(S_1) - F(S_2)] * VMT_{a,t} * K * P_t$$

where:

$E_t$	=	Reduction in automobile emissions
$F(S_1)$	=	Emission factor for speed $S_1$
$F(S_2)$	=	Emission factor for speed $S_2$
$S_1$	=	Speed before signal coordination program
$S_2$	=	Speed after signal coordination program
$VMT_{a,t}$	=	Regional VMT for year t, adjusted for the design year
$K$	=	Percent of regional VMT affected by the proposed program
$P_t$	=	Percent of program implemented in year t

The speed before signal coordination ( $S_1$ ) for the entire MARC region was estimated in the following manner and is shown in Table 8:

- 1) The average operating speed of vehicles in the AM, PM, and Off-peak (representing the rest of the day) on the 11 corridors on which travel time data was collected was determined.
- 2) The average operating speed by corridor on an average weekday was estimated using the weighted average of the AM, PM, and Off-peak speeds as shown below.

$$S_{\text{corr}} = S_{\text{am}} (\text{Vol}_{\text{am}}/\text{ADT}) + S_{\text{off}} (\text{Vol}_{\text{off}}/\text{ADT}) + S_{\text{pm}} (\text{Vol}_{\text{pm}}/\text{ADT})$$

- 3) The speed before signal coordination ( $S_1$ ) for the Operation Green Light project was estimated by taking a weighted average of  $S_{\text{corr}}$  for the 11 corridors (as shown in Table 8) based upon corridor VMTs. That speed ( $S_1$ ) was calculated to be 30.97 mph.

National data is available for estimating the improvements in average speed due to signal coordination (*Source: Transportation Control Measure Information Documents, U.S. Environmental Protection Agency, Office of Mobile Sources, March 1992*). This data was used for estimating the speed after signal coordination program ( $S_2$ ) from  $S_1$  in the following manner:

$$S_2 = S_1 \text{ raised by the \% improvement in speed}$$

Table 9 presents the percent improvement in speed data used for estimating  $S_2$ . The percentage of the various categories currently existing on the Phase 1 corridors was estimated using the traffic signal inventory data discussed in Chapter 3. Some jurisdictions currently have interconnected signal systems using their own timing plans, while other areas do not have interconnected signal systems. Thus, the improvement in travel speed along the Phase 1 corridors after deployment of Operation Green Light Phase 1 was predicted to be 17 % since this was the average between the two Before Conditions in Table 9 that are predominant in the region.

**Table 9. Traffic Signal Improvements**

<b>Before Conditions</b>	<b>After Conditions</b>	<b>Improvement in Speed or Time</b>
Non-Interconnected, Pre-Timed Signals with Old Timing Plan	Computer Based Control	25%
Interconnected, Pre-Timed Signals with Old Timing Plan	Computer Based Control	18%
Non-Interconnected Signals with Traffic-Actuation	Computer Based Control	16%
Interconnected, Pre-Timed Signals with Actively Managed Timing	Computer Based Control	8%
Interconnected, Pre-Timed Signals with Various Types of Master Control and Timing Plans	Optimization of Signal Timing Plans	12%

*Source: Urban and Suburban Highway Congestion, Working Paper No. 10, Washington D.C., FHWA, December 1987.*

The regional total of 48,500,000 vehicle-miles of travel was obtained from MARC. The VMT on the Phase 1 implementation project was estimated by multiplying the length of each Phase 1 corridor by the estimated average daily traffic (worksheet included in Appendix). The percent of regional VMT affected by the proposed program (K) was be estimated in the following manner:

$$K = \text{VMT on Phase 1 Corridors} / \text{Total Regional VMT}$$

It should be noted that the present MOBILE 5 version is not capable of estimating emission factors for time periods less than a full day (such as for peak periods). Therefore, the reduction in automobile emissions was estimated for an average day.

## 8.6 RESULTS

After deployment of Phase 1 of Operation Green Light, a significant reduction in Hydrocarbon and Carbon Monoxide emissions along the project corridors should result. Table 10 summarizes the expected results for full system implementation which includes Phase I, IIA, IIB, IIC, V and VI as described in the Implementation Plan. Table 11 summarizes the predicted change in emission after the implementation of the Phase 1 of Operation Green Light (Phases I, IIA, IIB, and IIC of the Implementation Plan).

**Table 10. Reduction in Emissions at Full System Implementation**

Emission Type	Emissions Without Any System	Emissions After System Implemented	Change
	(Grams)	(Grams)	(Grams)
Hydrocarbons	17,688,961	16,074,867	-1,614,094
Carbon Monoxide	133,073,094	114,336,388	-18,736,706
Nitrous Oxides	21,379,668	21,568,451	+188,783

**Table 11. Reduction in Emissions After Implementation of Phase 1**

Emission Type	Emissions Without Any System	Emissions After System Implemented	Change
	(Grams)	(Grams)	(Grams)
Hydrocarbons	7,259,550	6,597,126	-662,424
Carbon Monoxide	54,613,198	46,923,653	-7,689,545
Nitrous Oxides	8,774,216	8,851,692	+77,476



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# **APPENDIX A**

## **MARC Corridors Listing**



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# **APPENDIX B**

## **Additional Non-MARC Study Corridors**

# APPENDIX C

## Regional Signal Management Strategies

- o Web Research Sites
- o Las Vegas Model



## Web Research Sites

Additional web sites that will provide information for the Traffic Engineering community are listed below. Not all these sites contain information regarding regional Traffic Signal Timing but have been included to provide comprehensive information:

[Traffic Signal Association](http://tsa.cc) <http://tsa.cc>  
[America Walks](http://www.webwalking.com/amwalks/) <http://www.webwalking.com/amwalks/>  
[American Public Works Association](http://www.pubworks.org/) <http://www.pubworks.org/>  
[Highway Capacity Manual WebSite](http://www.hcmweb.net/) <http://www.hcmweb.net/>  
[Intermodal Assoc. of N. America](http://www.intermodal.org/) <http://www.intermodal.org/>  
[International Parking Institute](http://www.parking.org/) <http://www.parking.org/>  
[Pedestrian Bicycle Safety Research](http://www.tfsrc.gov/safety/pedbike/pedbike.htm) <http://www.tfsrc.gov/safety/pedbike/pedbike.htm>  
[Pedestrian Safety Roadshow](http://www.ota.fhwa.dot.gov/walk/) <http://www.ota.fhwa.dot.gov/walk/>  
[Perils for Pedestrians](http://www.pedestrians.org/) <http://www.pedestrians.org/>  
[Urban Mobility Network](http://www.mobility-net.com/) <http://www.mobility-net.com/>  
[Transportation Education-Garrett A. Morgan-USDOT/FHWA](http://www.dot.gov/edu/) <http://www.dot.gov/edu/>  
[Colorado DOT](http://www.dot.state.co.us/business/) <http://www.dot.state.co.us/business/>  
[ITE](http://www.ite.org/) <http://www.ite.org/>  
[Bike/Ped Interests](http://tcsp-fhwa.volpe.dot.gov/evalguid.doc) <http://tcsp-fhwa.volpe.dot.gov/evalguid.doc>  
[Automated Enforcement](http://www.photocop.com) <http://www.photocop.com>  
[Center for Transportation Research and Education](http://www.ctre.iastate.edu/) <http://www.ctre.iastate.edu/>  
[National Transportation Library USDOT](http://www.bts.gov/ntl/browse.html) <http://www.bts.gov/ntl/browse.html>  
[The Turner-Fairbank Highway Research Center](http://www.tfsrc.gov/) <http://www.tfsrc.gov/>  
[Transportation Resources \(Princeton University\)](http://dragon.princeton.edu/~dhh/) <http://dragon.princeton.edu/~dhh/>  
[National Work Zone Safety Clearinghouse](http://wzsafety.tamu.edu/) <http://wzsafety.tamu.edu/>  
[Highway Capacity Manual Web Site](http://www.hcmweb.net/) <http://www.hcmweb.net/>  
[Strong Concepts](http://strongconcepts.com/) <http://strongconcepts.com/>  
[McTrans Information Center](http://www-mctrans.ce.ufl.edu/info-cen/info-cen.htm) <http://www-mctrans.ce.ufl.edu/info-cen/info-cen.htm>  
[AASHTO Home Page](http://www.aashto.org/) <http://www.aashto.org/>  
[FHWA Home Page](http://www.fhwa.dot.gov/) <http://www.fhwa.dot.gov/>  
[Transportation Research Board Home Page](http://www.nas.edu/trb/) <http://www.nas.edu/trb/>  
[Innovation Briefs](http://www.innobriefs.com) <http://www.innobriefs.com>  
[University of South Florida, Center for Urban Transportation](http://www.cutr.eng.usf.edu) <http://www.cutr.eng.usf.edu>  
[District 5 ITE](http://www2.ncsu.edu/unity/lockers/project/southerndite) <http://www2.ncsu.edu/unity/lockers/project/southerndite>  
[Ga ITE Section](http://www2.ncsu.edu/unity/lockers/project/southerndite) <http://www2.ncsu.edu/unity/lockers/project/southerndite>  
[ITE-British Columbia](http://www.islandnet.com/ITE_BC) [http://www.islandnet.com/ITE\\_BC](http://www.islandnet.com/ITE_BC)  
[District 6 ITE](http://www.westernite.com) <http://www.westernite.com>  
[Viggen Corp](http://www.viggen.com) <http://www.viggen.com>  
[City of Ventura](http://www.ci.ventura.ca.us/meet/depts/traffic) <http://www.ci.ventura.ca.us/meet/depts/traffic>  
[TENC 9804](http://www.leeengineering.com/tenc9804/index) <http://www.leeengineering.com/tenc9804/index>  
[ITE TENC List Serve](http://www.leeengineering.com/tenc9804/index) <http://www.leeengineering.com/tenc9804/index>  
[Manual of Traffic Signs](http://members.aol.com/rcmoeur/signman.html) <http://members.aol.com/rcmoeur/signman.html>  
[ADOT Traffic Group](http://www.dot.state.az.us/ROADS/traffic/index.htm) <http://www.dot.state.az.us/ROADS/traffic/index.htm>



[American Public Works Association](http://www.pubworks.org/apwa/) <http://www.pubworks.org/apwa/>  
[Intermodal Assoc. of N. America](http://www.intermodal.org/) <http://www.intermodal.org/>  
[International Parking Institute](http://www.parking.org/) <http://www.parking.org/>  
[Pedestrian Bicycle Safety Research](http://www.tfhr.gov/pedbike/sherwood2.htm) <http://www.tfhr.gov/pedbike/sherwood2.htm>  
[Pedestrian Safety Roadshow](http://www.ota.fhwa.dot.gov/walk/) <http://www.ota.fhwa.dot.gov/walk/>  
[Perils for Pedestrians](http://www.pedestrians.org/) <http://www.pedestrians.org/>  
[Urban Mobility Network](http://www.mobility-net.com/) <http://www.mobility-net.com/>  
[Lighting and Traffic Signal Manufacturers](http://tsa.cc/svc/ts_link1.htm) [http://tsa.cc/svc/ts\\_link1.htm](http://tsa.cc/svc/ts_link1.htm)  
[AASHTO Home Page](http://www.aashto.org) <http://www.aashto.org>  
[ATMS Discussion Forum](http://www.itsonline.com/atmsforum/index.html) <http://www.itsonline.com/atmsforum/index.html>  
[Department of Justice ADA Home Page](http://www.usdoj.gov/crt/ada/adahom1.htm) <http://www.usdoj.gov/crt/ada/adahom1.htm>  
[Iowa Access Management Awareness Project](http://www.ctre.iastate.edu) <http://www.ctre.iastate.edu>  
[ITE Traffic Engineering Archive](http://foxtrot.pti.psu.edu/PTI/students/ITE/index1.asp) <http://foxtrot.pti.psu.edu/PTI/students/ITE/index1.asp>  
[ITS Electronic Document Library](http://www.its.fhwa.dot.gov/cyberdocs/welcome.htm) <http://www.its.fhwa.dot.gov/cyberdocs/welcome.htm>  
[Manual on Uniform Traf Control Devices](http://www.ohs.fhwa.dot.gov/devices/mutcd.html) <http://www.ohs.fhwa.dot.gov/devices/mutcd.html>  
[National Motorists Association](http://www.motorists.org) <http://www.motorists.org>  
[National Work Zone Safety Clearinghouse](http://wzsafety.tamu.edu) <http://wzsafety.tamu.edu>  
[Office of Highway Information Management Home Page](http://www.fhwa.dot.gov/ohim) <http://www.fhwa.dot.gov/ohim>  
[Texas Transportation Institute](http://tti.tamu.edu/index.stm) <http://tti.tamu.edu/index.stm>  
[Traf Manual](http://www.amtrakcalifornia.com/hq/traffops/signtech/signdel/chp4/chap4.htm) <http://www.amtrakcalifornia.com/hq/traffops/signtech/signdel/chp4/chap4.htm>  
[Welcome to Walkable Communities](http://www.walkable.org) <http://www.walkable.org>  
[Roundabout Traf Control Info Center](http://www-uftrc.ce.ufl.edu/wwwround/rnd-home.htm) <http://www-uftrc.ce.ufl.edu/wwwround/rnd-home.htm>  
[The Law and Traffic Calming](http://www.trans.ci.portland.or.us/Traffic_Management/Trafficcalming/Laws.htm) [http://www.trans.ci.portland.or.us/Traffic\\_Management/Trafficcalming/Laws.htm](http://www.trans.ci.portland.or.us/Traffic_Management/Trafficcalming/Laws.htm)  
[Index of Transportation Sites](http://transnet.ce.gatech.edu/tread/links/linkwww.htm) <http://transnet.ce.gatech.edu/tread/links/linkwww.htm>  
[Transportation Sites](http://www.sense.tutkie.tut.ac.jp/sites/trans-e.html) <http://www.sense.tutkie.tut.ac.jp/sites/trans-e.html>  
[Bicycle and pedestrian issues](http://www.odot.state.or.us/techserv/bikewalk/obpplan.htm) <http://www.odot.state.or.us/techserv/bikewalk/obpplan.htm>  
[Roundabouts](http://www.odot.state.or.us/techserv/engineer/pdu/Roundabout.htm) <http://www.odot.state.or.us/techserv/engineer/pdu/Roundabout.htm>  
[Roundabouts](http://roundabouts.kittelson.com/) <http://roundabouts.kittelson.com/>  
[Roundabouts](http://www.roundabouts.com/) <http://www.roundabouts.com/>  
[Traffic Calming](http://www.trans.ci.portland.or.us/Traffic_Management/TrafficCalming/) [http://www.trans.ci.portland.or.us/Traffic\\_Management/TrafficCalming/](http://www.trans.ci.portland.or.us/Traffic_Management/TrafficCalming/)  
[Research on alternate solutions](http://www.islandnet.com/~litman/) <http://www.islandnet.com/~litman/>  
<http://www.dot.gov/>  
<http://dragon.princeton.edu/~dhh/>  
<http://www.bts.gov/>  
<http://www.dot.ca.gov/>  
<http://lighting.lrc.rpi.edu/ltgtrans/led/>  
<http://www.ite.org/>  
<http://www.westernite.com/>  
<http://www.nas.edu/trb/>  
<http://www.atssa.com/>  
<http://www.aashto.org/>  
<http://www.npapark.org/>  
<http://www.nsc.org/>  
<http://www.iesna.org/>  
<http://www.dot.ca.gov/wwwindex.htm>  
<http://www.imsasafety.org/>



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<http://www.celsoc.org/>  
<http://www.autodesk.com/>  
<http://www.dca.ca.gov/pels/index.html>  
<http://www2.nas.edu/trbcrp/>  
<http://www2.nas.edu/trbcrp/22de.html>  
<http://WWW.HCMWEB.NET/>  
<http://WWW.XWALK.COM/>  
<http://WWW.MOTORISTS.COM/>  
<http://www.hwysafety.org/>  
<http://www.rkjk.com/>  
<http://www.econolite.com/>  
<http://www.webworldinc.com/idc-traffic/>  
<http://www.mmm.com/market/trans/index.html>  
<http://mctrans.ce.ufl.edu/>  
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# **APPENDIX D**

## **Signal Inventory Data**



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# **APPENDIX E**

## **CSPC Results**



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# APPENDIX F

## System Types & Summary



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# **APPENDIX G**

## **Operations & Maintenance Costs**



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# APPENDIX H

## Air Quality Data