ORNL/TM-12773

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Concept Definition of Traffic Flow Wide-Area Surveillance

Glenn O. Allgood
Regina K. Ferrell
Steve W. Kercel

INSTRUMENTATION & CONTROLS DIVISION

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM-12773

Instrumentation and Controls Division

CONCEPT DEFINITION OF TRAFFIC FLOW WIDE-AREA SURVEILLANCE

Glenn O. Allgood
Regina K. Ferrell
Steve W. Kercel

Date Published: July 1994

Prepared for the
FEDERAL HIGHWAY ADMINISTRATION
by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENTS

The members of this project team wish to acknowledge and thank the following individuals for their participation in the Wide-Area Surveillance Symposium sponsored by Oak Ridge National Laboratory on November 16–17, 1993. We appreciate their careful thought, preparation, and participation in the workshop.

John Andrews—Massachusetts Institute of Technology/Lincoln Laboratory
Adrian Tentner—Argonne National Laboratory
Ron Gilbert—Pacific Northwest Laboratory
Robin Morel—Los Alamos National Laboratory
John Morrison—Idaho National Engineering Laboratory
Philip Moynihan—Jet Propulsion Laboratory
Don Lucas—Lawrence Berkeley Laboratory

EXECUTIVE SUMMARY

Traffic management can be thought of as a stochastic queuing process where the serving time at one of its control points is dynamically linked to the global traffic pattern, which is, in turn, dynamically linked to the control point. For this closed-loop system to be effective, the traffic management system must sense and interpret large spatial projections of data originating from multiple sensor suites. The intent of the Wide-Area Surveillance (WAS) Project is to build upon this concept and define the operational specifications and characteristics of a Traffic Flow Wide-Area Surveillance (TFWAS) system in terms of traffic management and control. In doing so, the functional capabilities of a TFWAS will be mapped onto an operational profile that is consistent with the Federal Highway Administration's Intelligent Vehicle Highway System.

This document provides the underlying foundation of this work by offering a concept definition for the TFWAS system. It concentrates on answering the question: "What is the system?" In doing so, the report develops a hierarchy of specialized definitions (Appendix A).

With this in mind, a TFWAS system is defined as a surveillance system specifically intended to observe the overall roadway traffic flow pattern over a wide geographical area (defined in terms of the flow network). Primarily, it is a control transducer for a nonlinear, noncausal, time-variant traffic flow control system. Although not specifically a safety system, the TFWAS is expected to add safety to traffic flow control.

The TFWAS will be developed around a set of feature vectors, a list of features that mathematically describes the dynamic system. In this context, a current state feature vector will characterize the controllable parameters that describe traffic flow. A context feature vector will characterize the observable but not controllable parameters that describe the context. These feature vectors will be used by both humans and machines. Therefore, the system's output must be machine readable (discernible) for the traffic control system to use in making control decisions. The output must be convertible to a form allowing quick interpretation by humans at the Traffic Management Center.

The primary input data to the TFWAS system will consist of the outputs from multiple sensor suites that are fed into a dynamically reconfigurable input/output data bus. Several kinds of sensors will be used, with numbers and locations varying. Therefore, the system must have an ability to update the system's architecture definition as the sensor configuration changes. Other input data to the TFWAS system will be in the form of demands from the control system to restructure the output feature vectors (the control system deciding the structure). The TFWAS system will transform the input data flow into output data flow.

The concept definition limits the primary function of the TFWAS system to traffic flow surveillance, for which it will be optimized. Other intelligent vehicle highway system services may use the output data of the TFWAS, but these must not interfere with its primary function. As an example, law enforcement monitoring could successfully use the information originating from within the system, but this is fundamentally different from, and incompatible with, traffic flow surveillance.

The TFWAS system will not be expected to operate at a single-vehicle resolution unless absolutely required by the cognitive machinery of the system. A specific objective of the TFWAS system is to provide only that needed aggregate information necessary to manage and control traffic on an area-wide basis.

This document also identifies many contextual constraints for the system, the most important resulting from the system's interactions with the traffic control system and the Traffic Management Center. Safety concerns, effects of physical settings and environment, applicable technologies, externally imposed intelligent vehicle highway system architecture, cost, and public perceptions are other constraints.

Finally, the impact of the concept definition and the contextual constraints on the use of the system are discussed. This perspective is presented as a prelude to the development of the systems definition document.

1. INTRODUCTION

The Federal Highway Administration (FHWA) envisions an intelligent vehicle highway system (IVHS) of the future with sophisticated traffic management capabilities such as advanced intelligent traffic flow control, automated route guidance, and platooning.[1] These functions require highly advanced surveillance techniques to sense environmental and traffic conditions to develop an accurate picture of the current state of traffic flow in a wide area. This information and these data are essential for advanced intelligent traffic control algorithms.

Typically, present-day traffic surveillance techniques do not perform this function. They are usually point surveillance techniques that monitor vehicles passing through a single projected point. Several of these point systems could be integrated to provide a larger, yet limited, view of the traffic flow. This, in itself, is not sufficient to provide the needed information for the sophisticated traffic flow control system of the future. What is needed is a system that assimilates information over a wider spectrum of spatially distributed data.

The specific objective of this project is to assess the feasibility of a system to characterize total traffic flow at a level sufficient to support the needs of FHWA's IVHS. This concept of monitoring a larger section of roadway has been termed *Wide-Area Surveillance* (WAS).

The difference between point surveillance and wide-area surveillance can be illustrated as follows. Point surveillance can be envisioned as viewing a select portion of roadway through an opaque black sheet with a few holes cut in it to view specific points. Wide-area surveillance can be envisioned as observing the entire section of roadway from an unobstructed viewpoint at any particular time.

Wide-area surveillance can be accomplished by emulating the human cognitive process. For a human, this cognitive view of a traffic pattern is a trained, volitional, and instantaneous process. To assess the feasibility of designing a machine to perform the equivalent functional task, two important issues must be addressed.

First, the concept definition must be developed. That is, the question "What is the system?" must be answered. Second, the contextual constraints for the system must be identified. We must examine what will operationally constrain the system from the viewpoint of its interactions with the other systems, safety concerns, physical settings and environment, applicable technologies, cost, and public perceptions.

This document concentrates on determining the concept definition, the contextual constraints, and the effects of both on the system definition. By thoroughly examining these issues at the beginning, a robust, well-developed system definition will emerge. This process is illustrated in Fig. 1.

The definition of Traffic Flow Wide-Area Surveillance (TFWAS) system as well as other concept definitions that relate to the traffic surveillance problem and process are described in a hierarchal structure detailed in Appendix A. In addition to this, a preliminary list of TFWAS system functionality and system requirements is presented for reference in Appendix B.

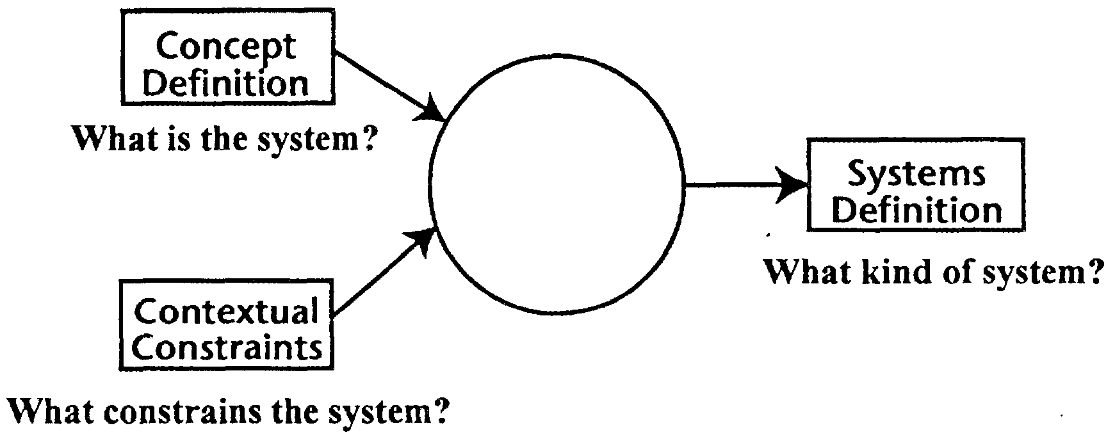


Fig. 1. Flow of ideas in this document.

2. CONCEPT OF THE TRAFFIC FLOW WIDE-AREA SURVEILLANCE

2.1 CONCEPT DEFINITION OF THE TFWAS

Five basic concept definitions are important in formulating the TFWAS system.

1. A wide area is a geographic environment of finite extent, within which attributes of ground vehicular traffic are monitored, processed, and managed to optimize the traffic movements with regard to throughput; safety; and environmental, economic, physical, and political constraints.

2. A surveillance system is a control transducer that operates by observing a scene. (Note: At the highest level of abstraction, a control scheme is represented as a control system, control actuators, and a control transducer. It is at this level of abstraction that the surveillance system is characterized as a transducer.)

3. A WAS system is one that observes a wide area, detects vehicle movement, and requires both a sensor suite and an integrating principle.

4. A traffic flow pattern is the overall pattern of the flow of many vehicles, revealing composite effects based on expectations and associative and nonassociative behavior patterns in a wide area. The idea of an overall pattern of traffic flow is illustrated in Fig. 2.

5. A TFWAS system is specifically intended to observe the overall roadway traffic flow pattern and provide specific information and data to the control system.

These five concept definitions are extracted from a hierarchy of definitions (Appendix A and Fig. 3) and make sense only when viewed from within this context. In light of this, a whole series of concept definitions, some depending hierarchically on others, is needed to support the overall TFWAS system structure. Some are required to understand the logical consequences of the concept of the TFWAS system; some are needed to propound its logically consistent system definition.

In this hierarchy, the root is at Level 1 and the lowest branch at Level 7. At the root level, each concept is defined in terms of well-known technical concepts. At each successive lower level, a concept is defined in terms of higher level concepts. Each successive level inherits definitions and attributes from the higher levels. The hierarchy, as defined, has no other meaning; it implies nothing about the operation, flow of control, or flow of information in a WAS system.

2.2 DERIVATION OF CONCEPT DEFINITIONS

The concept definitions listed in Appendix A are not arbitrary in nature but are based on a systematic and time-honored procedure for forming concept definitions. In Aristotelian logic, a concept definition consists of genus, the essential indication of the class to which the concept being defined belongs, and differentia, the essential indication of how the concept

Fig. 2. Overall traffic flow pattern.

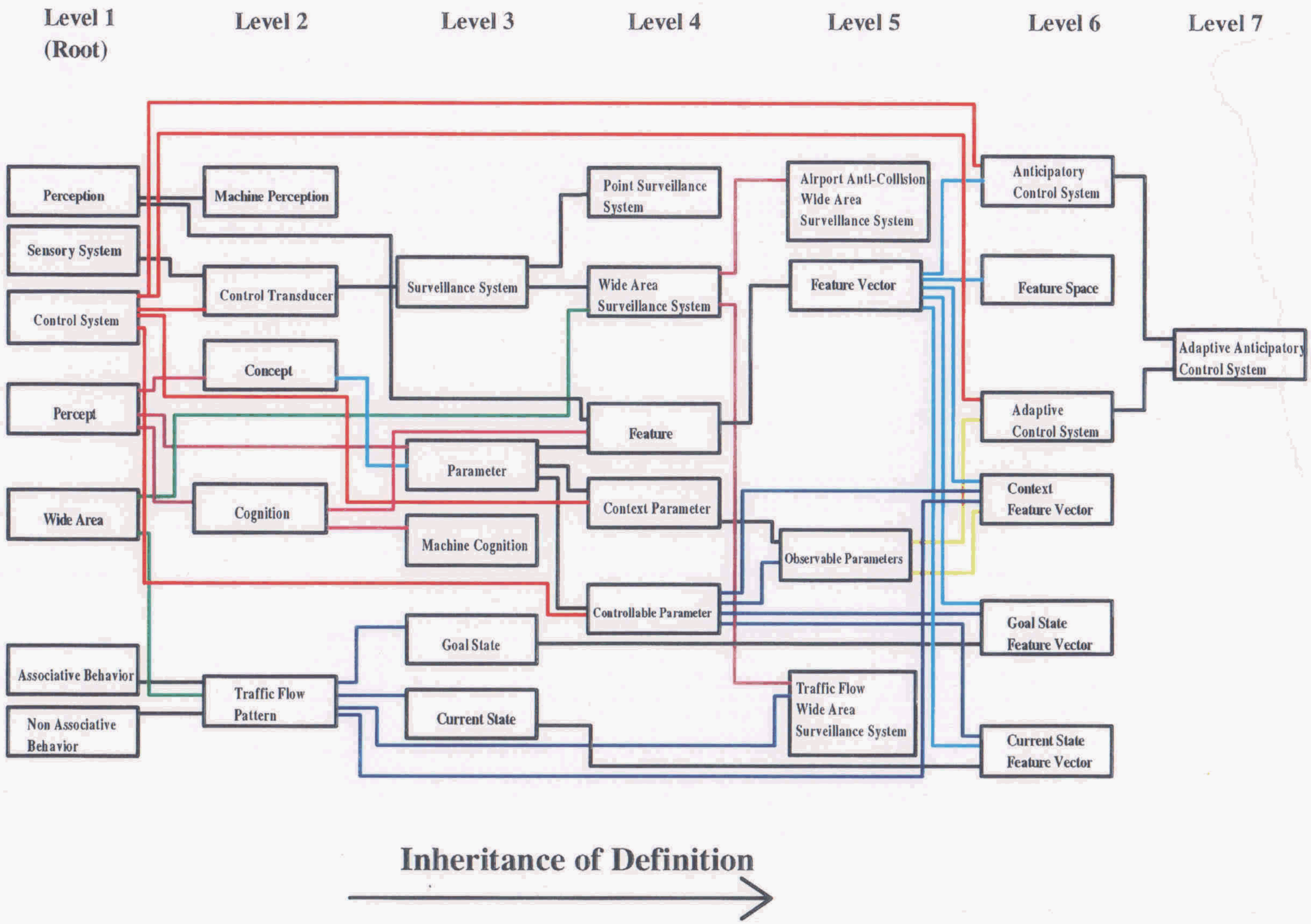


Fig. 3. Concept definition hierarchy.

being defined differs from others of its class.[2] Genus and differentia are not exhaustive lists of attributes; they include only those essential to the concept development.

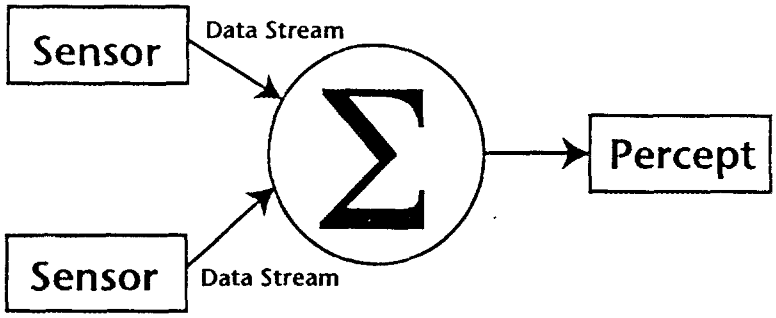
2.3 COGNITION AND PERCEPTION

The basic idea behind surveillance is observation and timely information dissemination. Thus, the TFWAS is inherently an observer within which the traffic flow patterns change as a result of its operations. This demands some level of machine intelligence. It is expected that this intelligence will be patterned after the perceptive and cognitive functions of human intelligence. Thus, some discussion of how perception and cognition operate is needed.

The human brain (or an intelligent machine) receives a high volume of noisy data in the form of analog electrical signals generated by external sources and sensed by individual elements. Unprocessed, these data constitute a meaningless stream of impulses. For humans, as well as the intelligent machine, the process of perception (Fig. 4) integrates raw information from the data stream and transforms it into percepts. This is a trained, automatic response. The process of perception is seeing things as they seem, whether they be percepts from a single data stream at different times or percepts from different data streams at the same time.

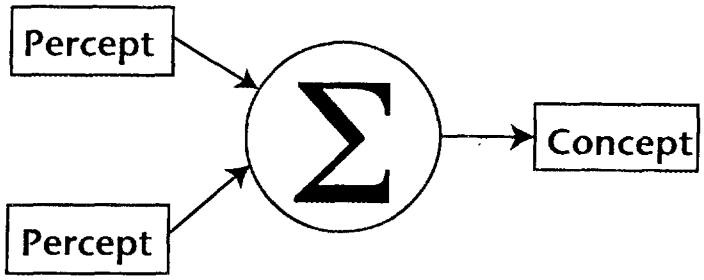
In the human and (possibly) in the intelligent machine, a higher level of discernment of reality exists. Multiple percepts are integrated into concepts, even though they may appear to contradict each other. This cognition (Fig. 5), or concept formation, is the process by which we see things as they are. Percepts provide the clues to underlying reality. Reconciling the clues and deducing the underlying reality is an act requiring thought. Given enough percepts and enough consideration of the logical implications of percepts and their interactions, the supposed contradictions are resolved, and a logically consistent understanding of the underlying reality is reached. Thus, we form a concept, or perform cognition.[3]

Ideally, the TFWAS system will perform such a feat of cognition. An array of smart sensors will automatically convert analog data streams into a set of percepts that are received unconditionally by the system. Although these percepts may appear to contradict one another, the system will determine the actual, consistent, and overall traffic flow. It will do so by finding a genus; its output indicates how this traffic flow is like other traffic flows. It will then find a differentia; its output indicates how this traffic flow is distinct from all the other possibilities. Thus, the system will form a consistent, well-internalized identification of the state of the traffic flow.



Perception = Process of discerning reality by low level integration of data flows

Fig. 4. Process of perception.



Cognition = Process of discerning reality by high level integration of percepts

Fig. 5. Process of cognition.

3. CONTEXTUAL CONSTRAINTS ON THE CONCEPT

A practical TFWAS system is constrained by many contexts, the most important being its intended application and use as an input transducer to a traffic control system. The next most important context is as a source of information for a traffic management center. In the following sections, these constraints are identified and defined in some detail.

3.1 INTERACTION OF THE TFWAS SYSTEM AND TRAFFIC CONTROL SYSTEM

3.1.1 Traffic Control System

The primary purpose of the TFWAS system is to provide input information to a traffic flow control system, possibly the Real-Time Traffic Adaptive Signal Control (RTTASC). RTTASC is a traffic control system that will modify its control actions in real time in response to the current state of traffic.[1] In this context, the TFWAS system continually updates and transmits to the traffic control system the current state feature vector, a list of attributes or functions that characterizes the present traffic flow through the defined wide area. The traffic control system will then compare the current state feature vector with the goal state feature vector, which is a list of attributes or functions that describe the most desirable traffic flow through the defined wide area. With this the system will compare the current state with the goal state and, based on the difference, initiate control actions to optimize traffic flow.

The traffic control system will be adaptive; that is, it will know that the goal state feature vector is sensitive to context, expressed as a context feature vector, and to the past history of the current state feature vector. Consequently, it will update the goal state feature vector on the basis of these two sources of information. Context consists of such things as weather conditions, time of day, and emergency preemption notices. It is a secondary (but necessary) role of the TFWAS system, on the basis of direct observations by its own sensors, to provide context information to the traffic control system.

The concept and systems definitions of the TFWAS system must be broad enough to accommodate very sophisticated control systems such as the RTTASC.[1] FHWA expects the RTTASC to be anticipatory, that is, to anticipate demand characteristics throughout the wide area. FHWA also expects it to perform machine cognition, resolving conflicts between seemingly contradictory sensor percepts.

Note the differentia of the two vectors generated by the TFWAS system. The current state feature vector consists of parameters that are both observable and controllable; control actions of the traffic control system can be expected to change them within some time constant. The context feature vector consists of parameters that are observable but not controllable; because they constrain control, the system must know about them, but it is not a function of the traffic control system to change them. An exception is when control actions may tangentially and gradually affect some context parameters, the time constant being extremely slow.

The TFWAS system and the traffic control system also interact as duals. Both the values in the goal state feature vector and the structure of the vector are variable. The structure of the current state feature vector must change in step, and remain compatible with, the goal state feature vector. When the traffic control system decides to change the structure of the state feature vectors, it notifies the TFWAS system. In response, the TFWAS system updates the structure of the current state feature vector. Thus, with respect to the specific contents of the current state feature vector, the TFWAS system is the transducer, feeding the data to the traffic control system which, in turn, makes control actions to change the current state feature vector. With respect to the structure of the current state feature vector, the traffic control system acts as the transducer feeding data to the TFWAS system, which takes the equivalent of control action to change the structure of the current state feature vector.

3.1.2 Traffic Management Center

According to the draft *National Program Plan for IVHS*,[1] the TFWAS system and the control system will interact with a human-operated Traffic Management Center (TMC). Thus, in addition to generating a machine-readable concept of the flow pattern, it will also generate data in a form that facilitates human interpretation of the flow pattern. These are two different problems. The TMC will use "human-in-the-loop" operation to override computer-generated control decisions.

3.1.3 Objectives of the Combined TFWAS/Control/TMC System

The objective of TFWAS is traffic control to maximize system throughput while minimizing delay, energy use, and air quality impacts—the target objective being to optimize people and traffic movement over a large geographic area.

With this in mind, the following functions of the TFWAS were developed based on the chapter on traffic control in the draft *National Program Plan for IVHS.*[1] The TFWAS' primary function will be to provide the current state feature vector to the traffic control system. Its secondary function, based on direct traffic observations by its sensors, will be to provide the context vector to the traffic control system. Its third function is to provide information to route guidance and mode selection services. Its fourth, and last, function is to provide information to other services such as law enforcement. An additional function may be to sell information to the public, but this is not considered a primary utility of the TFWAS.

3.2 SAFETY

The safety objective of the TFWAS system is "first, do no harm." That is, the TFWAS must not add risk from either a performance or a human user's standpoint. Within the purview of "first, do no harm," fail-safe considerations must be included. An example of fail-safe design is the requirement that a traffic control signal not display green in all directions when it fails.

TFWAS is a safe system, not a safety system. It is intended and expected that by improving the continuity of traffic flow, traffic control will become safer than at present. TFWAS does not include "safety system" as its genus. (This is in contrast to something like an airbag actuator that has the genus of a safety system.)

Because of cost, it is not realistic to specify an arbitrary level of safety *a priori.* Starting with an unsafe system, one can increase the safety at a small cost. The next increment of safety requires about the same increment of cost as the preceding one, but this process does not continue indefinitely. As a consequence of the economic law of diminishing returns, at a certain level of safety, the relationship saturates. Beyond this level, a large increase in cost is needed for a minuscule increase in safety.

3.3 OTHER CONTEXTUAL CONSTRAINTS

3.3.1 Physical Setting and Environment

Actual operation of the TFWAS system will depend on its physical setting and the environmental effects that occur within this setting. As examples, the environmental context includes ambient light levels, electromagnetic interference level, weather conditions, pollution conditions, and seismic conditions. These factors change with context-sensitive times ranging from hours to seasons. The sensitivity to environment dictates that the system be adaptive, that it change its response in step with the changing environment.

The sensitivity to physical setting means that a TFWAS system would operate differently in different settings such as urban expressways, interstate highways passing through small cities, and open-country highways. Physical settings are different, but they do not significantly vary with time. Sensitivity to setting can be addressed in two different ways. One would be to develop a whole series of TFWAS systems for each different kind of physical setting. The other would be to develop a hierarchical modular system that can be customized to a physical setting by judicious selection of modules.

3.3.2 The Place of the TFWAS System and the Flow Control System in the IVHS Architecture

In general, the global information flow drives the configuration of the IVHS architecture. This, in turn, impacts the local information flow into and out of each subsystem. These local information flows will then drive the architecture of each subsystem. Thus, in the case of the TFWAS system, its information flows are very much affected by its place in the IVHS system architecture.

To meet the goal of automated traffic control, FHWA envisions three interacting systems—wide-area surveillance, flow control systems (RTTASC), and traffic management centers. A change in any one affects the other two. Therefore, the design of any one system must be compatible with and take into account its interactions with the other systems.

The TFWAS/Control/TMC system will use "human-in-the-loop" operation to override computer-generated control decisions.[1] The view of the state of traffic flow generated by the TFWAS system must not cause information overload of the operator.

Provision for operator override raises several questions. Most notably, "What is the time for responding to human preemptions?" Also, "What is the time for the automatic control to recover from the human intervention after it has carried out the task ordered by the intervention?" In light of this, several key issues must be settled for the integrated TFWAS/Control/TMC system: How seriously does the machine take the human input? Is the human input absolute? Does the system drop what it is doing and do exactly what the human orders, or does it merely account for the human demand as part of its overall context? Finally, to what extent does the machine try to guess what the human meant to tell it?

In addition, the system must allow for automatic preemption by other services. (How long does it take to clear a path? Is this a controllable parameter?) Based on this, the system must know the recovery-from-preemption times and the probability distribution of each. This points to the need for an in-depth statistical analysis of the mean time between preemption parameters. (For example, do they tend to come in widely spaced clusters? Also, is the distribution context sensitive? Is the relationship of the distribution of preemptions as a function of the context features known?) If the recovery-from-preemption time is long and if the occurrence of preemptions is frequent, then there is the risk that the traffic management system will be in a perpetually chaotic state of preemption.

In summary, the critical architectural issue is that the design of the TFWAS system is primarily for a traffic flow monitoring function. If the system is designed to provide every conceivable attribute of every object in the wide area, it will fail. Other purposes must be incidental. The final words on traffic management in the draft *National Program Plan for IVHS* provide useful guidance: "It is assumed that the Traffic Control Service will provide the real-time transportation network performance data that many other IVHS services will use." We are developing the feature and context vectors needed for the flow control system and the cognitive picture needed by the TMC. This information may be tangentially useful to other services, and, if so, they will have access to it. However, we are not developing information for anything but traffic control. Any nontraffic control features that add to the cost, complexity, or risk of the system must be avoided.

3.3.3 Evolution out of the Existing Highway System

The design of the TFWAS system architecture must take into account the fact that it will be implemented in the existing highway system in an evolutionary fashion. This requirement has two practical implications. First, the sensor suite selection must take into account existing features of the infrastructure (e.g., metal signs that might block radar systems or impede the view of machine vision systems). Second, to the extent practicable, the TFWAS system should make use of the existing point surveillance sensors installed in the infrastructure. This, in itself, presents several problems. For example, although a given point sensor may function satisfactorily, it might not provide information needed by the TFWAS system. In such a case, it is not cost-effective to go to extraordinary lengths in the TFWAS system design to retain the existing sensor. In addition, an existing sensor that provides useful information to the TFWAS system will eventually fail. When it does, it may be more cost-effective to replace it with a different kind of sensor in a different location instead of a direct replacement.

The TFWAS system design must include a dynamically reconfigurable sensor interface. Hardware should be provided to interface a variety of sensors to a general input/output (I/O) data bus in the TFWAS system. Software drivers should also be provided for each interface, along with an interface engine that can determine what sensors are on the system. The system must be designed so that sensors can be automatically removed or installed.

This evolutionary implementation drives the architecture in another way. The system will start to be implemented by deploying small TFWAS systems that are expected to grow. I/O interfaces that are easy to expand and processing algorithms that are scalable will be required. An algorithm whose execution time grows factorially as a function of area may work perfectly to monitor one intersection but fail when expanded to monitor four at once.

Growth has another implication: development of interconnectivity that will allow integration of small, local TFWAS systems into a cohesive system. Upward compatibility with dynamically reconfigurable control must be included in the system from the beginning. That is, when several TFWAS systems grow until they begin to merge with each other, it should be an easy transition to integrate them into a single system when the context demands it, to run them autonomously when the context demands it, and to switch back and forth as conditions change.

3.3.4 Applicable Technology and Physical Realizability

Seven distinct enabling technologies are involved in implementing the TFWAS/Control/TMC system: sensor technology, communications technology, machine cognition, control strategy, systems design, large-scale systems integration, and human factors. Each will be discussed in the following section.

FHWA is aware of sensor technologies, including inductive loops, infrared sensors, microwave sensors, radar, magnetic, ultrasonic, machine vision, probe vehicles, and environmental sensors. These will be expanded upon in the forthcoming TFWAS Systems Definition Document.

Communications technology is relevant to the TFWAS system in that the communication link has finite bandwidth, which could reduce the information contained in the data packets. TFWAS system performance will be limited if the communications links do not deliver all the needed information and data generated by the sensors. An alternative view is that bandwidth requirements of the TFWAS system will drive the bandwidth requirement of the communications link and, consequently, the type of communications technology required. (Selection of sensor suite and control technology is incidental to the central goal of the concept definition and development of the TFWAS system.) Because of this, development of distributed intelligence and control for data fusion and bandwidth reduction will be needed.

The key technical problem of the TFWAS system is the integrating principle, which is expected to be machine cognition. The need for such an integrating principle is a distinguishing characteristic of the system. From comments in the draft *National Program Plan for IVHS,* it is evident that FHWA recognizes that this principle is where current technology falls short and major advances are needed. They also recognize that it is their role to directly support development of advancements in this area.

The selection of sensor suites and communication protocols comes down to providing the necessary information needed for the machine to conceptualize the traffic flow pattern. Therefore, context, realizability of sensors, and communications links should not constrain the TFWAS configuration. If this happens, the system may limit how much machine cognition is possible. Therefore, cognition must feed the control strategy that takes the following time constant issue into account. The TFWAS communicates with a traffic control system that operates control actuators. The control actuators include traffic control signals; reconfigurable signs with lane control indicators; and ramp access systems featuring lights, gates, and ramp metering. Most of these require time for the driver to notice them, to make a decision to respond, to seek the opportunity to perform the response, and, finally, time for the vehicle to actually move into a new position. A practical consequence of this is that the traffic flow pattern may change slowly.

Eventually, the system will evolve into one that feeds information into route guidance and mode selection systems. This evolution will not be included in the initial implementation, but with a modular open architecture, these features can be realized in the future. Note that even when available, this service is expected to have the desired effect of reducing overall congestion and creating a more favorable context in which to operate the traffic control system.

In an even later evolution of the traffic control system, the smart highway could directly control the smart car. In this case, control actuations mean that the traffic control system has physical control of individual vehicles. This implementation is decades in the future, but the initial implementation of the TFWAS system and traffic control system needs to address this in terms of upward compatibility.

In addition to the communication issues, there are two distinct human factors problems that must be solved to realize a workable TFWAS/Control/TMC system. One is the human–machine interface problem at the TMC, which affects the TFWAS system in that it must provide to the TMC cognitive information that makes sense to the human operator. The second human factors problem is the control strategy. Most control actuations consist of changing signs and signals to effect a driver response. The design of signs and signals that actually cause the human driver to carry out the desired action is critical to the success of the overall system.

Note that, with the exception of vehicles specifically equipped as probes, the vehicles in the system are passive—they do not explicitly communicate data to the system. As such, the control system has only implicit control over driver actions. The driver may or may not do what the smart sign says to do.

3.3.5 Cost

The TFWAS system definition assumes that for the next several decades all the intelligence (except for probe vehicles) needed for the system will be in the infrastructure, not the vehicle. Thus, the direct costs will be paid by governments or institutions such as turnpike authorities and not the consumer. Institutions usually base financial decisions on life cycle cost rather than selling price. On the other hand, consumers usually base financial decisions on selling price and ignore life cycle cost. Consumers making the decision whether or not to buy a TFWAS system are therefore more sensitive to overall cost than to selling price.

The main consideration for the purchaser of such a large capital system is, "Does it pay for itself?" That is, does the lifetime financial benefit offset the life cycle cost? If it does, the consumer will buy it. Although estimating the life cycle cost may be practical, the benefit may be more difficult to estimate; that is, how is the increase in throughput projected? What is the incremental financial value of an incremental increase in throughput?

On a related issue, although selling price is not the dominant issue, it must be taken into account. There is a capital cost for construction of an interstate highway. If the up-front price of the TFWAS system is a significant fraction of this, consumers may be reluctant to procure it, no matter how well justified the life cycle costs vs benefits are.

Maintenance costs may also be a significant element in life cycle cost. The implication is that relatively little maintenance should be required, and the design should make maintenance as inexpensive and as convenient as practicable. Because prevention is less costly than cure, the system should include incipient failure detection.

3.3.6 Nontechnical Issues

3.3.6.1 Liability

The TFWAS system will have the same liability problems as other IVHS systems. Who is responsible for damages (real and imagined) resulting from improper operation of the system? Is there a limit on liability? Is the risk of liability so great that the system is impractical to deploy? These and other issues will need to be addressed and resolved.

Legal issues of fairness also exist. No matter how the system is deployed, a statistical argument that it is unfair to some group is always possible. This possibility seems insignificant, but the argument could create lengthy delays in the deployment of the TFWAS system and traffic control.

3.3.6.2 Privacy and ownership

There are some compelling reasons for not using TFWAS system outputs for anything other than traffic flow control. First, to have the system sell information to the public could lead to litigation over who owns the information, what rights are conveyed by ownership, invasion of privacy, and liability for damage due to disclosure (accurate or inaccurate) of information generated by the TFWAS system.

Similarly, the use of TFWAS system information by law enforcement services could lead to several problems. To begin with, innocence is presumed under law. The use of electronic surveillance for traffic enforcement is interpreted by many as violating the right to privacy upheld by the Ninth Amendment to the U.S. Constitution. Because of the constitutional presumption of innocence and the requirement for proof beyond a reasonable doubt, the technical requirements for a law enforcement surveillance system would be vastly different from those of a traffic flow control system.

A cognitive surveillance system can integrate poor-quality percepts into a flow concept that is adequate for efficient and safe traffic flow control. In contrast, an automated law enforcement system is fundamentally different. A legal decision to use the force of law against a citizen would require excellent individual percepts from individual machines. The validity of a single percept depends critically on the sophistication, condition, and cost of the machine doing the perceiving. In fact, the idea that TFWAS will be "Big Brother" is a major obstacle to public acceptance. None of the first three functions of TFWAS—traffic flow control information, context information, and route guidance information—require that individual vehicles on the road be identified. All functions are concerned with the group vehicle patterns. If the lower two functions—law enforcement and public sale of information—are excluded, operating the surveillance system at a level of resolution that could identify specific vehicles is unnecessary. This fact could be a major issue in public acceptance of the TFWAS system.

3.3.6.3 Public perception

Three issues in public perception need to be addressed. First, "Is the public getting value for its money?" The answer depends on the capability of TFWAS and traffic control to make it noticeably easier for travelers to reach their destinations. Second, "Is privacy being safeguarded?" The answer depends on using a system that tracks aggregate flow patterns but not individual vehicles. Finally, "Is the system perceived as safe?" This issue is the most difficult to resolve; it has some technical solutions but is primarily an issue of perception.

The safety issue has some interesting precedents, as the nuclear power industry has found. It is not enough to be safe—the system must be considered to be safe. Because the system definition presumes that the road is smart but the cars are not, the TFWAS system will perform active sensing. That is, it will sense on the basis of its interpretation of the scattering of some kind of emanation. Even machine vision systems operate on the basis that the scene scatters ambient light. Lasers, radars, ultrasonics, and even magnetic loops emit some form of energy. Whatever sensors are used, their emanation levels should be kept at a minimum acceptable level, consistent with reliable operation of the sensor.

The other technological issue, which is beyond the scope of the TFWAS system development but possibly a key to the success of it and other elements of IVHS, is the serious study of the vulnerability of humans to the energies radiated by IVHS sensors. Scientific proof that the emission levels are safe, combined with a competent public relations effort, may go a long way toward allaying public fears.

3.3.6.4 Jurisdiction

FHWA envisions the system as being expandable over an extended geographic area. As such, it will cross jurisdictions. Therefore, it must operate in a seamless manner. This requirement is probably a more difficult problem than designing the control hierarchy to be dynamically reconfigurable.

4. IMPACT OF CONCEPT AND CONTEXT ON SYSTEMS DEFINITION

Concept definition identifies what the system is, while the context defines the constraints under which it must operate. The system definition, on the other hand, is the description of an implementation of a concept in a given context. The following is a description of the logical impacts of the concept and context on the TFWAS's definition.

4.1 RELATIONSHIP BETWEEN CONCEPT DEFINITIONS AND SYSTEMS DEFINITION

The system definition does not affect concept definition; it is the other way around. Concept definition considers the essential attributes that identify and distinguish a TFWAS system. The logical implications of concept definition act as a driving force for the system definition. Therefore, the system definition is involved with particulars of the design constrained by the context.

The reason for discussing systems definition at this point is that, with the concept definition and intended application established, a formal TFWAS architecture can follow. Of the immediate implications for the systems definition, the most notable are discussed in Sects. 4.2 to 4.7.

4.2 OBJECTIVES OF THE SYSTEM

In the best of all worlds, FHWA wants to optimize the proper mix of speed, people flow, vehicle flow, fuel consumption, and emissions. These factors are all observable and may be controllable.

With this as an established goal, the TFWAS will be developed around a set of feature vectors, a list of features that mathematically describes a physical effect. In this context, a current state feature vector will characterize the controllable parameters that describe traffic flow. A context feature vector will characterize the observable but not controllable parameters that describe the context. These feature vectors will be used by both humans and machines. Therefore, output must be machine readable; the traffic control system will use it to make control decisions. This requires that the format be convertible to a human-readable output at the TMC.

The primary input data to the TFWAS system will consist of the outputs of the sensor suite, as fed into a dynamically reconfigurable I/O data bus. Several kinds of sensors will be used, with variable numbers and locations of each. Therefore, the system must have an ability to reconfigure the system's hardware profile in response to changing demands based on sensor requirements. The other input data to the TFWAS system will be the demand from the control system to restructure the output feature vectors. The TFWAS system will transform the input data flow into output data flow.

The concept definition limits the primary function of the TFWAS system to traffic flow surveillance, for which it will be optimized. Other IVHS services may use the output vectors of the TFWAS, but these must not interfere with the primary function. As an example, law enforcement monitoring is fundamentally different from and incompatible with traffic flow surveillance.

The TFWAS system will not be expected to operate at single-vehicle resolution unless absolutely required by the cognitive machinery of the system. A specific objective of the TFWAS system is to provide the needed information that will allow control on an area-wide basis. Specifically, FHWA wants to avoid fragmented and conflicting control strategies within an area.

4.3 INTEGRATING PRINCIPLES

Integrating principles include both the information-extracting principle and the major attributes of the system. The information-extracting principle of the TFWAS system is expected to be machine cognition. In this context, the TFWAS system must be adaptive, may be anticipatory, with no assurance of linearity. In its intended application, it will be in a symbiotic and dualistic relationship with a nonlinear, noncausal, time-variant traffic flow control system.

4.4 MEASURES OF SYSTEM PERFORMANCE

The TFWAS System Definition Document will propose an overall performance index for the system. The performance index will be an integral part of a formalized definition of success of the system.

At a more detailed level, the performance of the system will be characterized by its time constants, including, but not limited to, the following:

1. The traffic control system time constant, which is a key constraint on what control actions are realistic, represents the time required for the system to respond to a control action when the system is under automatic control. We can observe it (implicitly) with TFWAS, and it constrains us. We cannot control the time constant with TFWAS.

2. The human preemption time constant is the time required for the system to respond to human preemptions by TMC operators.

3. The human preemption recovery time constant is the time needed for the automatic control to recover from the human intervention.

4. The machine preemption time constant is the time necessary for responding to machine preemptions by other automatic IHVS systems such as emergency response services.

5. The human preemption recovery time constant is the time required for the automatic control to recover from intervention by other machines.

All these time constants are context sensitive.

4.5 OBSERVABLE AND CONTROLLABLE PARAMETERS

The system definition presumes that the road is smart but the cars are not. Therefore, the TFWAS will receive all its information from what it senses and what the traffic control system tells it in the form of observable and controllable parameters. Establishing a method for identifying controllable and observable parameters and a set of criteria for assessing their acceptability will be done in the TFWAS System Definition Document.

Vehicle miles traveled through the wide area per unit time is a frequently desired output parameter. In the draft *National Program Plan for IVHS*, FHWA indicates that relative traffic load on different roadway segments is an important observable parameter and a key to control. According to the draft *National Program Plan for IVHS*, as part of the study of wide-area surveillance, FHWA seeks to evaluate measures such as accuracy, reliability, and coverage area for different surveillance methods.

During system definition, other parameters will need to be identified. These parameters may include density, complexity, and extent of the traffic flow. In addition to these, composite flow properties such as slug position, velocity, and acceleration will be needed. Statistical measures of vehicle separation also may be key parameters. Systems measures such as approach queue length and serving time may be other key parameters.

4.6 DYNAMIC RECONFIGURABILITY

FHWA anticipates that the traffic control system will have a dynamically reconfigurable architecture. It expects, but does not demand, that the architecture be hierarchical.[1] A practical implication of this is the need for the system to be modular.

Based on this requirement, three kinds of reconfigurability can be identified. The first is reconfigurability of the sensor suites (sensors are easy to install or remove). The second is reconfigurability of the control hierarchy (multiple systems need to operate as one; other times operate autonomously); and the third is reconfigurability of information flows in real time in response to a changing context.

4.7 RELIABILITY

The reliability of the system and its components is an issue. Part of the system performance measure will be what fraction of time the cognitive machinery and the individual sensors are available and doing work. In this context, the system will include incipient failure detection. That is, it will monitor its subsystems and detect the trends that indicate that, while the subsystem is still operating within acceptable limits, it will fail soon. This monitoring will improve the reliability of the system by allowing changeouts or bypasses before the failure occurs. It will also reduce maintenance costs by indicating what parts of the system actually need maintenance.

The modularity and reconfigurability of the system will allow it to route around subsystems that have either failed or are about to fail. This reconfigurability, combined with the robustness of the cognitive machinery (cognition does not require perfect or complete sensor data), should preclude the need for a major backup system. Unless everything fails at once, the system should not experience catastrophic failure.

5. CONCLUSIONS

A TFWAS system is a surveillance system specifically intended to observe the overall roadway traffic flow pattern over a wide area. Viewed in the context of the hierarchy of concepts depicted in Fig. 2 and described in Appendix A, this definition is logically consistent.

This concept must be applied to a specific context. Primarily, it is a control transducer for a nonlinear, noncausal, time-variant traffic flow control system. Although not specifically a safety system, the TFWAS is expected to add safety to traffic flow control. In addition, available technology, physical setting, externally imposed intelligent vehicle highway system architecture, and other considerations act as constraints.

The concept definition and the contextual constraints imply the foundation of the system definition (Fig. 6). Based on this, a systems definition will be constructed detailing the major functional requirements of the TFWAS system (listed in Appendix B). This definition will be developed in the next project task and will include a systems analysis covering objectives, attributes, and parameters of TFWAS; an evaluation of possible sensor and communications technologies; and a system's analysis defining operational and functional constraints. Following this will be a task to assess the impact of TFWAS on traffic control. The concept and systems definition will provide a foundation for work on the effects of this new surveillance technique on present and future traffic management strategies.

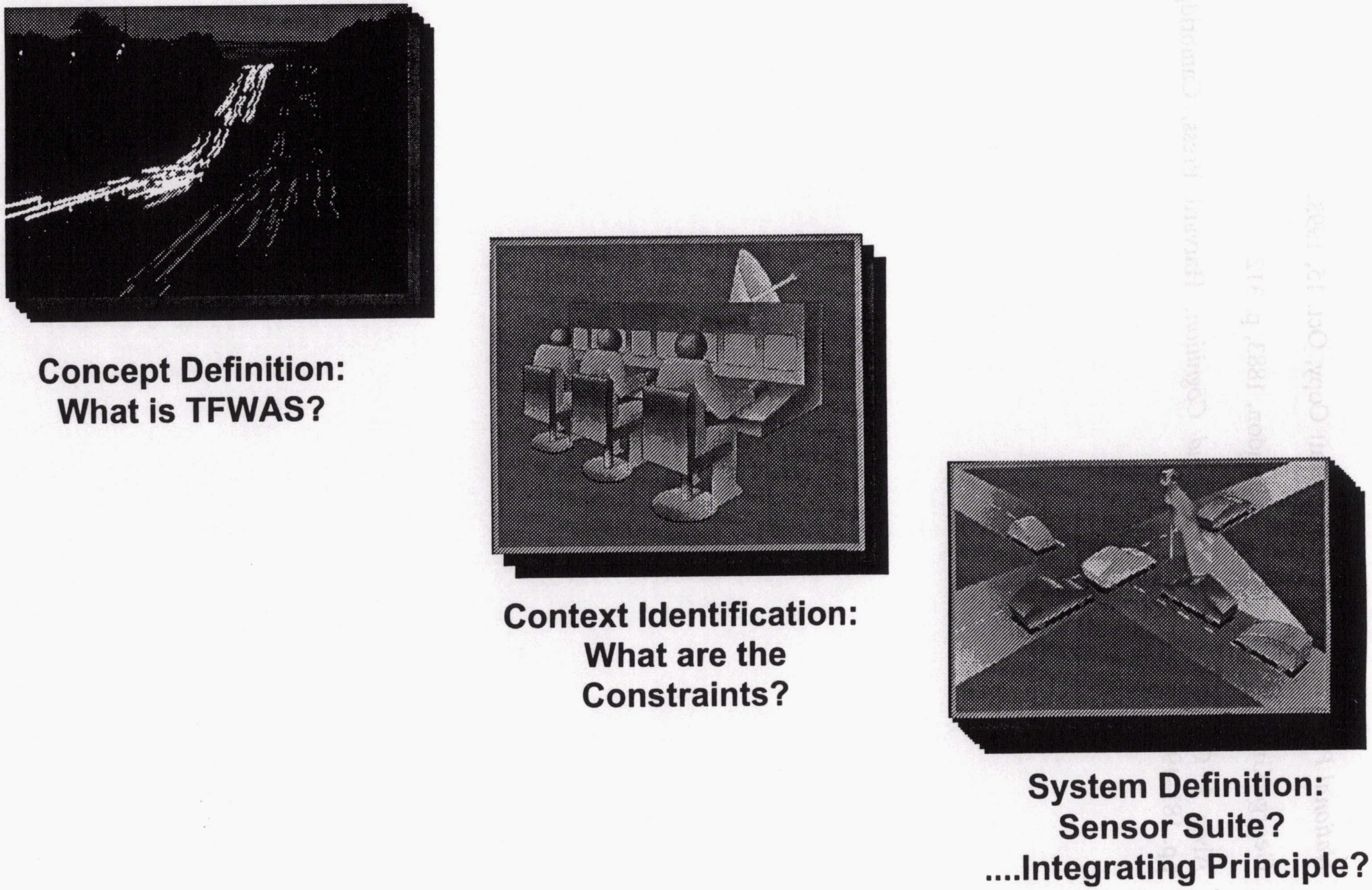


Fig. 6. Concept definition, constrained by context, identifies foundation of system definition.

REFERENCES

1. *National Program Plan for IVHS*, Draft Copy, Oct. 15, 1993.

2. George Grote, *Aristotle*, Murray, London, 1883, p. 312.

3. Alvin I. Goldman, *Epistemology and Cognition*, Harvard Press, Cambridge, 1986, pp. 181–198.

Appendix A

HIERARCHY OF CONCEPTS

The following is a hierarchy of concept definitions that are necessary in order to interpret this document. Figure A.1 is a diagram of the hierarchy.

A.1. HIERARCHY LEVEL 1

A.1.1 Perception

Genus = Process for discerning reality.
Differentia = Integrates data flows at a low level of complexity, reveals things as they seem.

A.1.2 Percept

Genus = Description of reality.
Differentia = Output information resulting from the integration of data flows at a low level of complexity, a glimpse of things as they seem.

Comments:

Differing percepts of an underlying reality may appear to contradict each other.

A percept is incidentally the output of the process of perception. However, it is not necessary to define either concept in terms of the other.

A.1.3 Control System

Genus = Electromechanical system.
Differentia = Specifically intended to change one or more physical phenomena.

A.1.4 Wide Area

Genus = Geographic environment.
Differentia = Of finite extent, within which attributes of ground vehicular traffic are monitored, processed, and managed to optimize the traffic movements with regard to throughput, safety, environmental, economic, physical, and political constraints.

Comments

A finite area is a two-dimensional region, not a single-point region, and not the whole universe. The fact that a wide area consists of a two-dimensional region that excludes these two extremes is a necessary part of the differentia. For a specific application, in the systems definition, a more restrictive set of bounds may be imposed on the extent of a wide area.

We had originally identified traffic flow as the specific attribute to be observed and optimized. However, this is too restrictive to be part of the differentia of a high-level definition. For example, if traffic flow were part of the differentia, then the Massachusetts Institute of Technology (MIT) airport surveillance system would be excluded from the concept. The MIT system observes an area immediately surrounding the airport runway. It tracks individual vehicle movements rather than composite flows. It primarily minimizes collisions, rather than maximizing flows. The concept definition of *wide area* must be broad enough to include the MIT system.

Also, the idea that something (e.g., flow) about vehicle movements in the wide area is to be optimized, without identifying that something, is a necessary part of the differentia. In the high-level concept definition, it is more accurate to say that throughput is one of the optimizing constraints than to say that flow is the specific thing being optimized in the wide area.

It is arguable that it is enough to say that something is being optimized under constraint and that it is not part of the essential differentia to list the specific constraints. However, if it can be argued that a specific list of constraint is necessary to differentiate a wide area from some other kind of geographic environment, then the entire list must be included in the differentia.

A.1.5 Associative Behavior

Genus = Learning process.
Differentia = Identifies causal connection through repeated exposures to the connection.

A.1.6 Nonassociative Behavior

Genus = Learning process.
Differentia = Changes sensitivity to a phenomenon on the basis of many exposures to unrelated instances of the phenomenon.

A.1.7 Sensory System

Genus = Electromechanical system.
Differentia = Specifically intended to provide a mathematical output correlated with one or more physical effects.

A.2 HIERARCHY LEVEL 2

A.2.1 Machine Perception

Genus = Perception.
Differentia = Performed by a machine.

Comment

Perception may be good if the sensor is good (and costly). Perception may be poor with an inexpensive sensor.

A.2.2 Concept

Genus = Description of reality.
Differentia = Output information resulting from the process of integrating percepts at a high level of complexity.

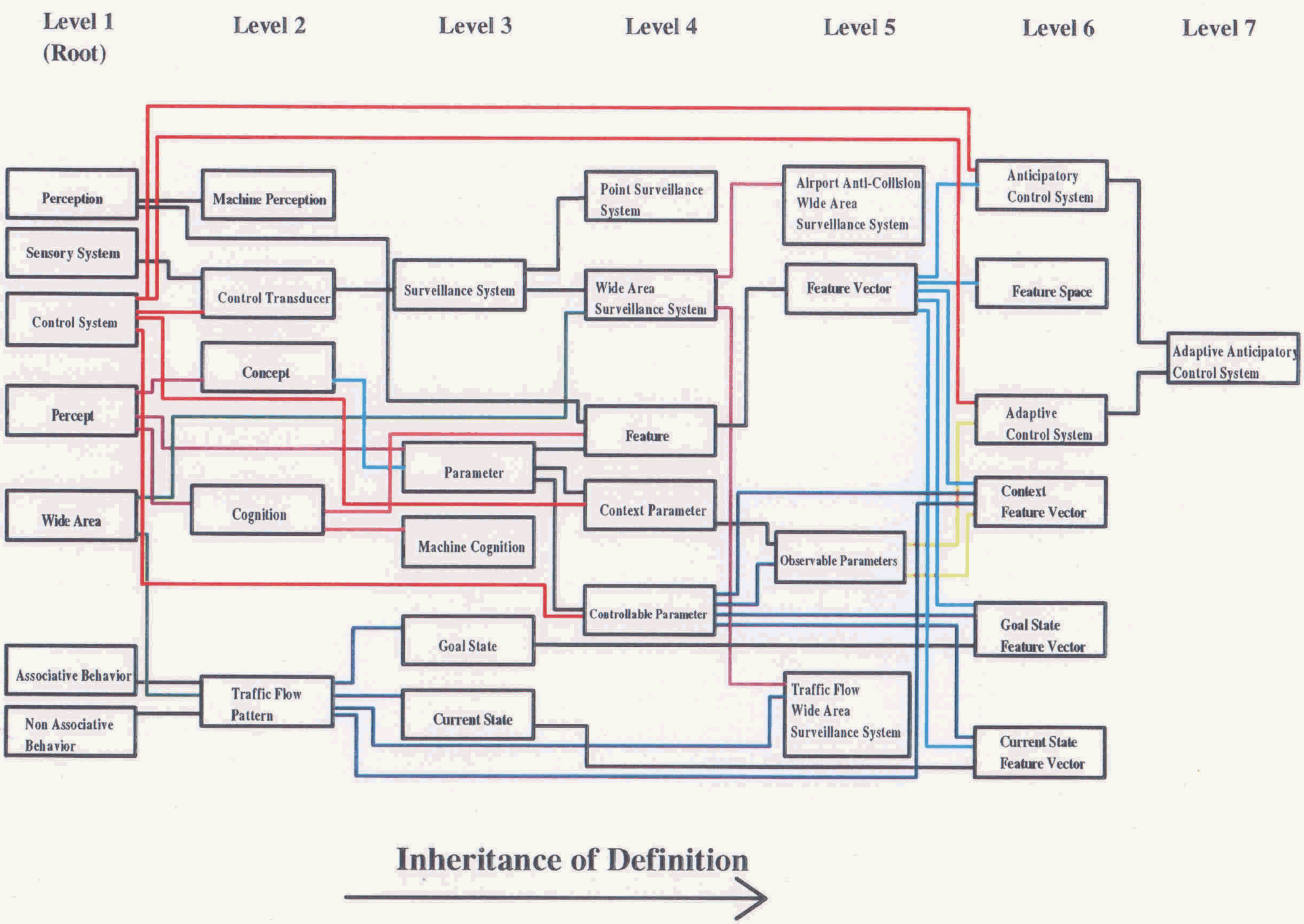


Fig. A.1. Concept definition hierarchy.

Comments

A concept is logically consistent. It resolves how seemingly contradictory percepts fit together to describe the identity of a thing that is single and whole.

A.2.3 Cognition

Genus = Process for discerning reality.
Differentia = Integrates percepts at a high level of complexity, reveals things as they are.

A.2.4 Control Transducer

Genus = Sensory system.
Differentia = Specifically intended to provide input to a control system.

A.2.5 Traffic Flow Pattern

Genus = Overall pattern.
Differentia = Reveals the composite effects of the flow of many vehicles on the basis of expectations and associative and nonassociative behavior patterns in the wide area.

Comments

Traffic flow is concerned with more than the movements of individual vehicles However, the system might use percepts of movements of individual vehicles as part of the cognitive process of determining the overall flow pattern.

A.3 HIERARCHY LEVEL 3

A.3.1 Surveillance System

Genus = Control transducer
Differentia = Operates by observing a scene.

Comment

This observation may be, but is not constrained to be, made by a vision system

A.3.2 Machine Cognition

Genus = Cognition
Differentia = Performed by a machine

Comments

Whether performed by a machine or a human, the essential idea of cognition is the integration of percepts to reveal the underlying picture of reality. It is possible to obtain a good concept of reality by integrating a group of percepts, each of which is of poor quality.

The human brain does this constantly. Whereas good machine perception requires good sensors, good cognition can succeed with inexpensive sensors and a good cognition algorithm. Thus, a good machine perception system always has a high hardware cost per unit. Whereas good cognition might use inexpensive hardware, it might have a high one-time information development cost that can be spread out over many duplicates of the system.

A.3.3 Parameter

Genus = Mathematical quantity or measurement.
Differentia = Strongly correlated with physical attributes of a concept or a percept.

A.3.4 Goal State

Genus = General description of traffic flow pattern.
Differentia = If traffic were flowing as well as possible.

Comments

The state refers to a general description of the physical phenomenon. It is broader than the mathematical description.

A.3.5 Current State

Genus = General description of traffic flow pattern.
Differentia = As traffic is actually flowing.

Comment

The state refers to a general description of the physical phenomenon. It is broader than the mathematical description.

A.4 HIERARCHY LEVEL 4

A.4.1 Feature

Genus = Parameter.
Differentia = To be used as input to a process of perception or cognition.

Comment

Features, organized into a feature vector, can be the output of a cognitive control transducer.

A.4.2 Context parameters

Genus = Parameters.
Differentia = Not directly affected by control actions of the control system.

Comments

In a time-invariant control system, the context parameters would be absolutely independent of control actions, and the constraints they impose could be hardwired into the system.

In an adaptive control system, the context parameters may be indirectly affected by control actions (e.g., the system reduces flow density; the reduction of flow density eventually reduces the ambient lead level). As the system becomes aware of the changing context and the changing constraints the context imposes, the system dynamically updates its control characteristics to meet the new constraints.

A.4.3 Controllable Parameter

Genus = Parameters.
Differentia = Directly affected by control actions of the control system.

Comments

Note that this is a *definition* of controllable parameters; it is not a *specification* of controllable parameters. It is part of the system definition, not the concept definition, to decide which controllable parameters the transducer must sense and the control system must affect.

A.4.4 Wide Area Surveillance System

Genus= Surveillance system.
Differentia = Observes a wide area, detects vehicle movement, requires both a sensor suite and an integrating principle.

Comments

A wide area, defined elsewhere, is the specific thing that this kind of system observes. It is a necessary part of the differentia of WAS. In particular, *wide area* differentiates the system from a *point* surveillance system.

WAS might track the movements of individual vehicles. It might track the movements of a group of vehicles as a group without needing to know the individual movements. The necessity, but not the specific kind, of movements being tracked is part of the differentia of WAS.

The sensor suite may have many elements or as few as one. Even if it has only one sensor in a one-street town at the end of a box canyon, sensor data plus contextual knowledge are integrated to give the wide area movement tracking. The necessity, but not the specific kind, of an integrating principle is part of the differentia of WAS.

A.4.5 Point Surveillance System

Genus = Surveillance system.
Differentia = Counts vehicles passing through a single point.

Comments

The inductive loop detector is a point detector. In one of several intended applications, Minnesota Autoscope is used as a point detector.

It is logically permitted, but not required, that a WAS system include point surveillance systems in its sensor suite.

A.5 HIERARCHY LEVEL 5

A.5.1 Feature Vector

Genus = List of features.
Differentia = Mathematical description of a physical effect sufficient for the intended application.

Comments

The feature vector may be as simple as a single number or as complex as a dynamically reconfigurable list of functions. The effect described by the feature vector might be either a concept or a percept.

A.5.2 Observable Parameters

Genus = Parameters.
Differentia = Includes both context parameters and controllable parameters.

Comment

The concept of observable parameters includes everything that can be sensed by the transducer, whether or not the control system can affect them.

A.5.3 Traffic Flow Wide-Area Surveillance System

Genus = Wide-area surveillance system.
Differentia = Specifically intended to observe the overall roadway traffic flow pattern.

Comments

This particular kind of surveillance system is used to feed a feature vector to a traffic flow control system. Other possible uses of the feature vector are tangential to its intended purpose. In a generic traffic flow wide-area surveillance system, it is logically permitted, but not required, to use the knowledge of movements of individual vehicles to deduce the overall flow pattern.

From the definition of wide area surveillance, an integrating principle is required. It is expected, but not required, that the integrating principle will be machine cognition. This fact is part of the system definition rather than the concept definition of the traffic flow wide-area surveillance system.

This system is not a general-purpose traffic detector. It is looking for the specific parameters needed for flow control (e.g., average vehicle spacing). It is not part of the concept definition or the system definition to define the system to sense parameters (e.g., specific vehicle identity) for nonflow-control services such as toll collection.

A.5.4 Airport Anticollision Wide-Area Surveillance System

Genus = Wide-area surveillance system.
Differentia = Specifically intended to track each of the moving vehicles/aircraft in a confined area at an airport for the primary purpose of preventing collisions.

Comments

The WAS developed by Lincoln Labs is a system of this kind. It meets the genus and differentia of a WAS system. The objective is to feed a collision avoidance system, with all other uses of the output being tangential. Thus, it is different in kind from the traffic flow WAS. In real-world deployment, many of the same kinds of things can go wrong with both kinds of systems. Therefore, we can benefit from the experience of Lincoln Labs. However, the traffic flow WAS is different from the airport anticollision WAS, and we expect to see a whole range of practical problems not encountered by Lincoln Labs.

A.6 HIERARCHY LEVEL 6

A.6.1 Anticipatory Control System

Genus= Control system.
Differentia = Noncausal, makes control decisions on the basis of its expectation of future values of feature vectors.

Comment

Deterministic noncausal systems (time machines, or systems taking action on the basis of specific knowledge of the future) are generally believed to be unrealizable. Real-world noncausal control systems (e.g., horseshoe crab brains) are stochastic. They take control actions noncausally on the basis of their best estimate of the future state of the feature vectors.

A.6.2 Goal State Feature Vector

Genus = Feature vector.
Differentia = Mathematical description in terms of controllable parameters of the goal state.

Comment

This vector is determined by the control system on the basis of its awareness of the context and past variations in the current state feature vector.

A.6.3 Current State Feature Vector

Genus = Feature vector.
Differentia = Mathematical description in terms of controllable parameters of the current state.

Comment

This vector is output from the control transducer and input into the control system.

A.6.4 Context Feature Vector

Genus = Feature vector.
Differentia = Mathematical description, in terms of observable but not controllable parameters, of contextual features that affect the current traffic flow pattern.

Comments

This vector is output from the control transducer and input into the control system. The current state feature vector and the context feature vector constitute the entire output of the traffic flow wide-area surveillance system.

A.6.5 Feature Space

Genus = Mathematical vector space.
Differentia = The set of all possible values of all the elements of a feature vector.

Comments

Value is more general than number. Features might include, but are not limited to, mathematical objects such as numbers, functions, or geometric figures.

A.6.6 Adaptive Control System

Genus = Control system.
Differentia = Time variant, dynamically updates its control characteristics on the basis of observable parameters and/or its own output.

Comments

The adaptive character of a system leads to a duality between the control transducer and the control system. Part of the adaptation is that the control system can restructure its feature vectors to meet the changing context. To do so, the control system must inform the control transducer what structure the feature vectors must take.

Two information flows run in opposite directions. The control transducer sends feature vectors to the control system, and as a result, the control system takes control actions. The control system sends the desired structure of the feature vectors to the control transducer, and, as a result, the control transducer restructures the feature vectors.

A.7 HIERARCHY LEVEL 7

A.7.1 Adaptive Anticipatory Control System

Genus= Control system.
Differentia = Simultaneously adaptive and stochastic anticipatory.

Comments

The traffic flow wide-area surveillance system is expected to serve as the control transducer for a control system that is both adaptive and anticipatory. This fact is too restrictive to make it part of the differentia of the concept definition of the traffic flow wide-area surveillance system, but it is a key element in the system definition.

Appendix B

PRELIMINARY LISTING OF TFWAS SYSTEM FUNCTIONAL DESCRIPTIONS AND REQUIREMENTS

The following is a listing of the TFWAS system's functional descriptions and requirements. These attributes will be expanded upon in the TFWAS Systems Architecture Document.

- Primary purpose of TFWAS system: input transducer for traffic flow control system.
- TFWAS is symbiotic and dualistic with the traffic flow control system. Changes in either one affect the other.
- Traffic flow control system is expected to be adaptive, anticipatory, and nonlinear.
- Primary function of TFWAS: produce feature vector characterizing traffic flow pattern (parameters that are both observable and controllable).
- Secondary function of TFWAS: produce feature vector characterizing context (parameters that are observable but not controllable).
- Lower level functions (e.g., input to mode selection systems, etc., must not interfere with the three major functions).
- Feature vectors must be readily convertible to human-readable form.
- TFWAS is affected by the following context sensitivities:
  - Physical setting (e.g., urban expressway, city street, rural highway).
  - Physical features of infrastructure.
  - Effects of environment on TFWAS.
  - Effects of TFWAS on environment.
  - Global intelligent vehicle highway system architecture.
  - Machine-induced preemptions.
  - Human-induced preemptions.
  - Evolutionary implementation.
  - Seamless operation across jurisdictions.
- Traffic flow pattern are extracted by machine cognition.
- Specific machine cognition algorithms are not yet identified.
- Cognition algorithms will require extensive development.
- TFWAS is a safe system but not primarily a safety system.
- TFWAS must both be safe and be seen to be safe.
- TFWAS will be hierarchical, modular, scalable, and dynamically reconfigurable.
- TFWAS will perform active sensing.
- Most vehicles in the system are assumed to be passive.

- Privacy and legal rights of travelers and users must be protected
- TFWAS is not expected to identify individual vehicles.
- System must include incipient failure detection.
- System must provide for automatic work-arounds for local failures.
- System must not be subject to global failure induced by single-point failure.
- System must be physically realizable with known sensor technologies.
- Life cycle cost must be low enough for TFWAS to pay for itself.
- TFWAS capital cost per mile must be a small percentage of highway construction cost per mile.
- TFWAS must be inexpensive and convenient to maintain.

INTERNAL DISTRIBUTION

1. R. A. Abston
2–6. G. O. Allgood
7. H. R. Brashear
8. B. G. Eads
9–10. R. K. Ferrell
11. D. N. Fry
12. R. B. Honea
13–14. S. W. Kercel
15. D. W. McDonald
16. D. R. Miller
17. G. N. Miller
18–19. A. K. Rathi
20. J. O. Stiegler
21. R. E. Uhrig
22. D. F. Craig
23–24. Central Research Library
25. Y-12 Technical Reference Section
26–27. Laboratory Records
28. Laboratory Records–Record Copy
29. ORNL Patent Section
30. I&C Division Publications Office

EXTERNAL DISTRIBUTION

31–33. Alberto J. Santiago, Branch Chief, Federal Highway Administration, Office of Safety and Traffic Operations R&D, HSR-11/Turner Fairbank Hwy. Res. Ctr., 6300 Georgetown Pike, McLean, VA 22101-2296
34. Assistant Manager for Energy Research and Development, DOE-ORO, P.O. Box 2001, Oak Ridge, TN 37831-8600
35. B. Chexal, Electric Power Research Institute, 3412 Hillview Avenue, Palo Alto, CA 94303
36. V. Radeka, Brookhaven National Laboratory, Instrumentation Division, 535-B, Upton, NY 11973
37. M. M. Sevik, Carderock Division, Naval Surface Warfare Center, Code 1900, Bethesda, MD 20084-5000
38. R. M. Taylor, Leeds and Northup, Sunneytown Pike, North Wales, PA 19454
39–40. Office of Scientific and Technical Information, U.S. Department of Energy, P.O. Box 62, Oak Ridge, TN 37831