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A REFERENCE ARCHITECTURE AND A CLASSIFICATION SYSTEM FOR AUTOMATED HIGHWAY SYSTEMS (AHS)* (DRAFT)

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Abstract

This report provides a reference architecture and a classification system for Automated Highway Systems (AHS). The reference architecture is hierarchical and modular, allowing for future expansion as needed. The architecture consists of function, form, and physical layers. An additional field known as the carrier, indicating the location of a given technology, e.g. in the roadway or in the vehicle, is also provided. The architecture is used as the basis for a classification system for AHS. AHS is a diverse and dynamic research area, and this classification provides a structured means of specifying an AHS. An overview of the architecture and the classification system is presented, followed by the detailed schematics for the AHS classification, including the functional areas of Driving, Structural Support, Traffic Separation, Vehicle/Road Interaction, and Power Source.

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1. Introduction

The field of Automated Highway Systems (AHS) is a diverse area of research. In the past, many system configurations and approaches have been proposed for an AHS. This diversity has increased due to the variety of studies currently being performed for the Federal Highway Administration (FHWA) Precursor Systems Analyses (PSA) of AHS. At this time, there does not seem to exist a unifying approach to the representation of an AHS that encompasses the currently proposed systems as well as foreseeable systems in an organized manner. The architecture presented here is an attempt to provide such a unified and organized reference architecture for AHS.

This architecture can be used in a variety of ways. It can be used to specify an AHS at the functional level, in terms of the general systems and approaches to be included, or it can be used to provide detail down to the specific physical components to be used. The nature of the architecture allows different users to focus on different aspects of the AHS. For example, a system designer with a DOT perspective could choose to focus specifically on areas that relate to the infrastructure, while a vehicle manufacturer could focus specifically on vehicle-related areas. In addition, the architecture, in its fullest sense, can be used as a detailed design specification for an AHS. With an AHS specified using the reference architecture, it would be possible to generate a bill of materials for the AHS, or for particular AHS subsystems. If additional information is added regarding properties of the individual components, e.g. component reliability statistics, it is possible to use the reference architecture to compute aggregate properties of subsystems, systems, and the complete AHS.

The architecture is expandable so that it can be customized to carry information required for a specific task. Here, we present a general overview of the reference architecture, followed by an application of the architecture to a classification of AHS, which at this time includes the functions of Driving, Structural Support, Traffic Separation, Vehicle/Road Interaction, and Power Source. This classification is currently being coded into Nexpert Object, in an effort to provide an expert system for AHS design and specification. This tool will provide a knowledge-based facility to aid in AHS research and analysis. The development of the Nexpert model is an ongoing effort.

The information in this document is based on a broad search of the existing AHS literature. Detailed reference information is not provided here; however, much of the information included here can be cross-referenced using (Lasky and Ravani, 1993). Information regarding structural support and traffic separation can be found in (Caltrans, 1992) and (Homburger and Kell, 1988). Additional information on structures has been obtained from (FHWA, 1994). Some of the details for various AHS sensors were found in (Martin Marietta, 1994). Additional component information and cross-references into the literature and product information can be found in (Lasky and Ravani, 1994). Finally, an overview of Group Technology Classification and Coding can be found in (Bedworth, Henderson, and Wolfe, 1991)

2. Overview of the Reference Architecture

The AHS Reference Architecture is a heirarchical, modular architecture. A general overview of the architecture is shown in Figure 1. At the top level, the architecture is divided into blocks based on function. AHS functions will include driving, for example. Functions can be added as needed, as the architecture is modular. Within the Function Level, there are sub-function layers as required. The next level down in the architecture is the Form Level, which indicates the general form of the technology that will provide the specified function. The Form Level can also have multiple internal layers. Below this is the Physical Level, which indicates the specific technology and equipment to be included in the system. At each level of the hierarchy, an additional property can be coded, indicating the location of the particular function or technology. This property is known as the Carrier. At this time, identified Carriers include the roadway, roadside, median, vehicle, and satellites. The Carrier is not included in the classification schematics in the appendices, but has been incorporated as a property in the Nexpert model.

With the above approach, the AHS Reference Architecture allows a broad range of detail in specifying an AHS. A researcher could designate a general functional level specification of an AHS, simply indicating the overall form for each of the functions, leaving the details of the physical implementation for later study. On the other hand, an AHS designer could use the same architecture to completely specify a system down to the level of the specific type of sensor to be used for headway sensing, for example. The architecture has been designed to be flexible, so that future technological and conceptual innovations in the area of AHS can be incorporated with minimal impact on the overall structure.

3. AHS Classification Based on the Reference Architecture

The architecture has been used to develop a classification system for AHS. The classification, like the architecture, is hierarchical. Choices made at the higher levels of the classification will constrain selections at the lower levels. However, every attempt has been made to minimize, and ideally eliminate, any dependencies across individual layers of the classification. This will allow easier enumeration of possible AHS configurations. With this feature, once codes are assigned at all layers of the classification, it is possible to enumerate all possible AHS Representative System Configurations (RSC's) to the required level of detail by simply cycling through all possible combinations of the codes. Note that this will yield an overwhelming number of RSC's if it is done for the entire classification. However, this feature can also be utilized at any level of the classification. For example, in a system that includes point follower control for longitudinal vehicle control, it would be possible to enumerate all available position sensing approaches. The hierarchical nature of the classificationwill be represented using a group technology hierarchical classification and coding scheme. The code digits will be grouped according to functional areas for easier identification.

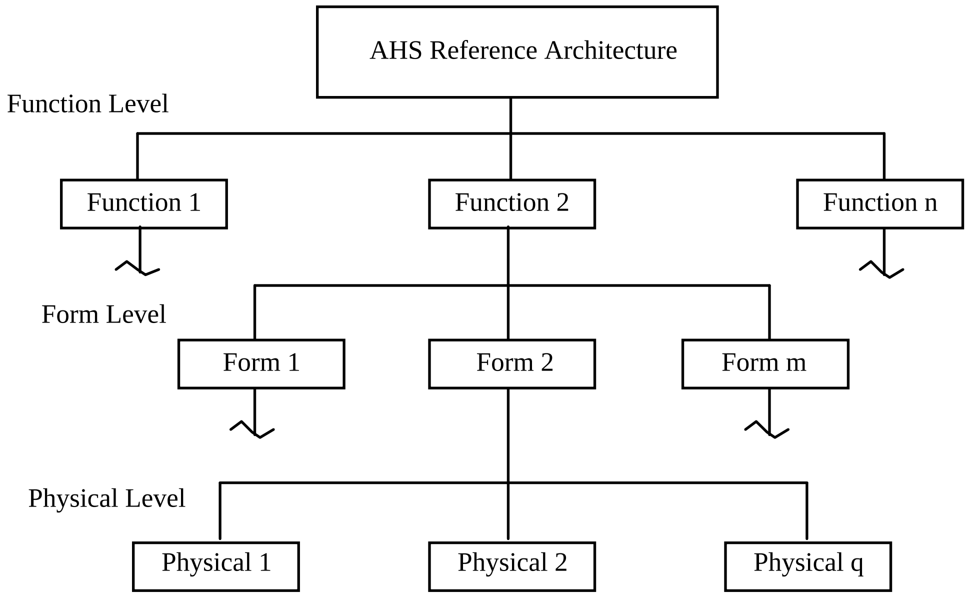

Figure 1: AHS Reference Architecture Format.

To provide a better feel for how the AHS Classification System works, Figure 2 shows a more detailed overview of the classification. In this figure, the actual functional areas are presented, along with some level of detail within each functional area. The amount of detail varies within each area based on two factors: the amount of information that appears needed at this time to specify an AHS, and the information that can be found in the relevant literature. For example, the function of Traffic Separation, here meaning separation of AHS and non-AHS traffic, lane delineation, and system entry and exit, requires

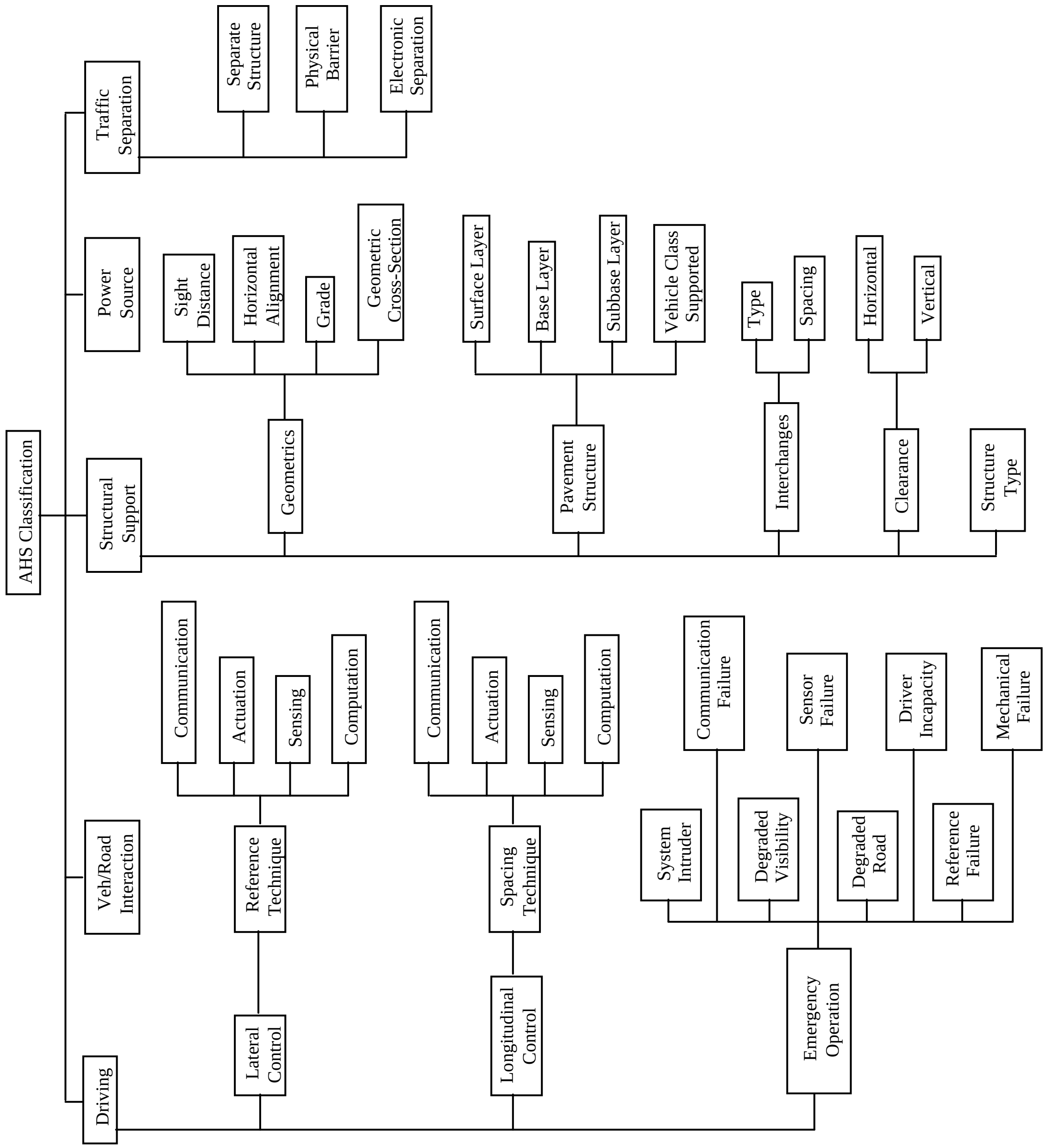

Figure 2: Detailed Overview of the AHS Classification.

significantly less detail than the area of automated driving. At the same time, there is far less discussion of this function in the literature when compared to the Driving function. Based on this, we have provided significantly more detail on the Driving function, and relatively less detail on the Traffic Separation function. As noted earlier, the detailed schematic diagrams for the AHS Classification are presented in the appendices.

4. AHS Classification Details

The complete code for the AHS Classification consists of a string of digits, providing a convenient and compact representation of the Automated Highway System and its components. The digits are grouped according to the hierarchy of Figure 2, with the details of the hierarchy given in the appendices. The main groupings are by function, so that the code can be broken down into groups of digits for the Driving function, the Structural Support function, the Traffic Separation function, the Vehicle/Roadway Interaction function, and the Power Source function. Each of these groups can be subdivided based on the information in the schematics. The top-level code grouping is shown in Figure 3. Each of the sub-groups in Figure 3, e.g. Longitudinal Control, will consist of a set of digits describing that sub-function.

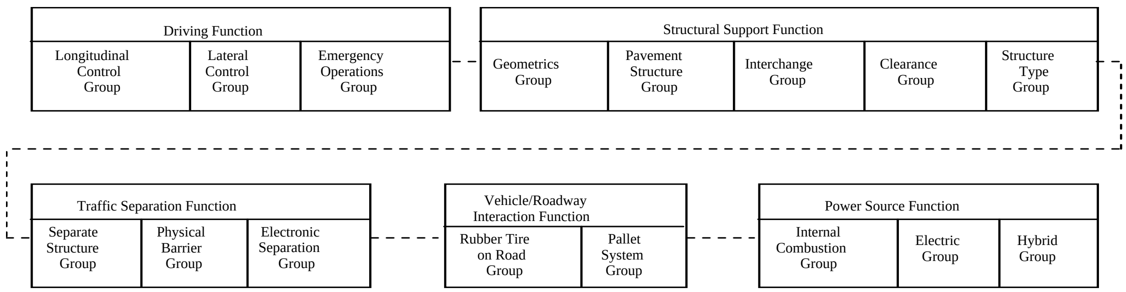

Figure 3: Top-Level AHS Classification Code Grouping.

The details of various code groups are given in the subsequent figures. Most of the code groups contain significant detail and are well-suited to further breakdown, e.g. the Lateral and Longitudinal Control sub-functions. The details of the Longitudinal Control code group are shown in Figure 4. The Lateral Control code group details are given in Figure 5. Emergency Operation code group details are given in Figure 6. The Structural Support function code group also bears further breakdown; details are shown in Figure 7. Finally, the Traffic Separation code group breakdown is shown in Figure 8. These figures present the breakdown of the code groups into blocks, but do not actually show the codes themselves, or the options within each of the blocks. Each of the groups of digits within the blocks will consist of one or more digits. For the details of the classification and coding, see the appendices.

<table>
<tr><td colspan="14">Longitudinal Control Group</td></tr>
<tr><td colspan="14">Longitudinal Control Form Block (Spacing Technique)</td></tr>
<tr><td colspan="4">Communications Block</td><td colspan="2">Actuation Block</td><td colspan="5">Sensing Block</td><td colspan="3">Computation Block</td></tr>
<tr><td colspan="2">VVC</td><td colspan="2">VRC</td><td rowspan="2">Throttle</td><td rowspan="2">Brake</td><td colspan="2">Abs. Posn. Sensing</td><td colspan="2">Rel. Posn. Sensing</td><td>Vehicle Sensing</td><td rowspan="2">Calculation</td><td rowspan="2">Data Acquisition</td><td rowspan="2">Communication</td></tr>
<tr><td>Point-to-Point</td><td>Broadcast</td><td>Point-to-Point</td><td>Broadcast</td><td>Translation</td><td>Heading</td><td>Headway</td><td>Closing Rate</td><td>Velocity
Acceleration
Roll / Pitch
Yaw Rate
Throttle Sensor
Brake Sensor
Status Sensors</td></tr>
</table>

Figure 4: Longitudinal Control Code Group.

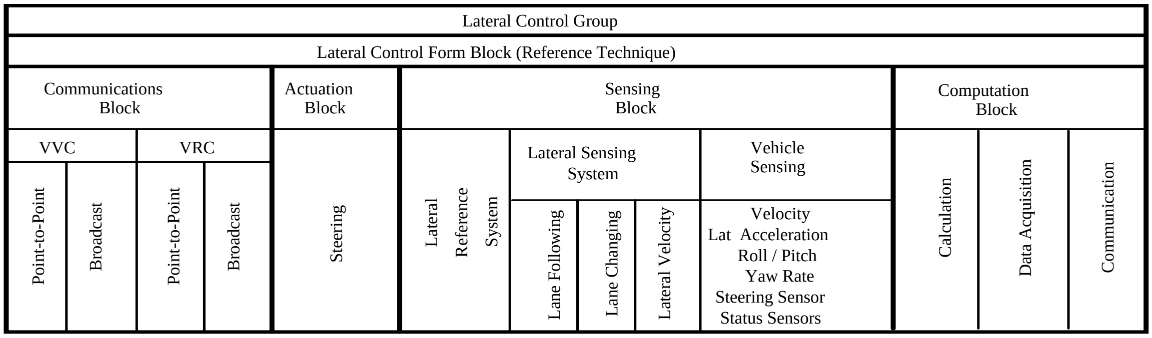

Figure 5: Lateral Control Code Group.

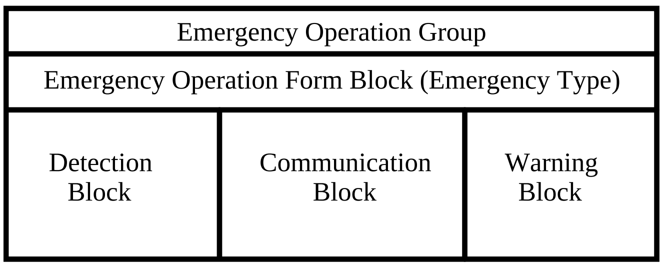

Figure 6: Emergency Operation Code Group.

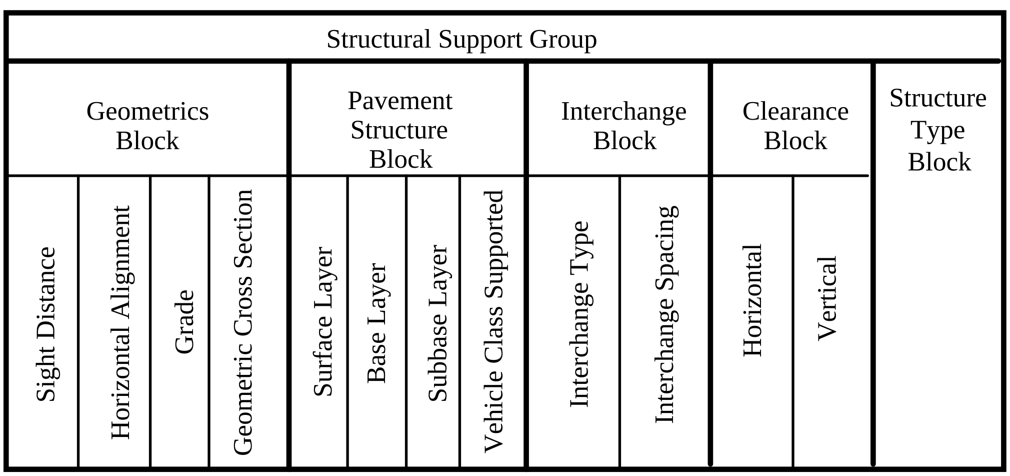

Figure 7: Structural Support Code Group.

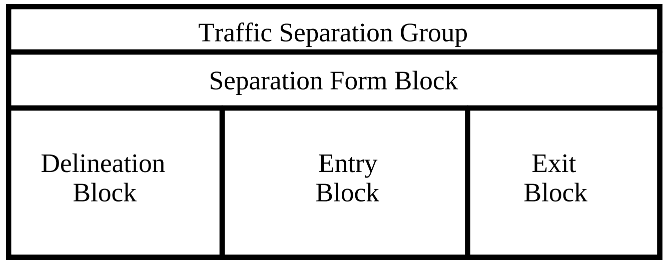

Figure 8: Traffic Regulation Code Group.

5. Comments on the AHS Classification Details

A number of areas in the detailed classification bear further discussion. Some areas have not been completely classified and coded; this may indicate topics that require further research before they are well-defined. Other areas require some clarification, as detailed commentary is not provided in the appendices. These issues will be discussed here.

In the specific area of sensing of absolute translation, a number of approaches have been listed. Most of these approaches can be classified as radio-navigation techniques. Within these, GPS is clearly the most likely candidate for application in an AHS. The other radio-navigation techniques, including Loran-C, Omega, TACAN, Transit, and TACTIC, are only included for completeness. On a related note, throughout this classification, GPS should always be considered Differential GPS, as differential operation will be required to achieve the desired accuracy.

The computational requirements for lateral and longitudinal control have only been roughly indicated. The needed areas include control law calculation, sensor data acquisition, and communication support. Once again, these areas will not be mutually exclusive. In addition, the detailed physical components in these areas have not been indicated, as they will vary considerably based on implementation, and may be significantly different in the future.

The areas of vehicle / road interaction and vehicle power have not been developed in detail in the reference architecture. Most of the AHS literature has assumed that interaction will be through rubber tires on the road; as such, the concentration here is on this case, and the architecture is strongly biased in that direction. The possibility of a pallet system has been included here for completeness, and as a provision for future expansion in the classification, if this approach appears more likely in the future. Vehicle power source has been included here, but again only in a cursory fashion. Most of the classification will be only minimally influenced by the choice of vehicle power technology, with the possible exception of roadway-provided electric power, which could have significant impact on other areas. Further information may be provided from other Precursor System Analysis studies in the area of Alternative Propulsion Systems.

Within Structural Support, the area of sight distance may require further investigation. The figures given in the three areas are taken from (Caltrans, 1992), and are based on human driver responses. At the very least, these numbers may need to be modified for the case of automated longitudinal control. In addition, the concepts themselves may require rethinking as they apply to an AHS. Passing distance will only be applicable in rural areas. The inclusion of "Unknown" as an option for these areas should alleviate any difficulties.

6. Conclusions

The AHS Reference Architecture and Classification System presented here can be used in many ways. The classification can be used to delineate AHS Representative System Configurations to the level of detail required. It can also be used to completely specify an AHS, down to the physical components to include in the roadway, the vehicle, and elsewhere, providing a complete bill of materials. The classification is currently being used to develop a knowledge-based expert system to aid in AHS research and analysis. It represents a unified classification of the current and foreseeable possible AHS configurations. Finally, the classification can be expanded to include additional functions as needed in the future. This is an important feature, as AHS research is still in its early stages, and many changes are likely over the coming years.

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