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Perspectives

Applying a System of Systems Approach for Improved Transportation

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The article represents the author's personal views.

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Abstract

Future national, commercial, and individual prosperity must rely on a global transportation schema that is dependable, efficient, safe and resilient. To be successful, this global transportation schema must accommodate the needs of local communities within the constructs of larger regional and national transportation systems and priorities. Success will also be measured by the ease with which the multi-level transportation solutions can work among themselves horizontally and vertically, and adapt to the emergence of new technologies and the retirement of old technologies. Without using a system of systems (SoS) approach, scarce private and public resources will be spent on products and infrastructure solutions that are not efficient, interoperable, nor upgradeable, and will hinder economic progress, national security, and individual movement for the next 50 years. Application of a SoS approach brings a single, unifying framework that provides order, simplification, and certainty for entrepreneurs, corporations, small businesses, researchers, urban planners, logisticians, and individuals. Developed as an open set of system and sub-system architectures, such an approach will identify a supporting set of standards, interfaces, best practices, and design guides to foster new and innovative inter and intra-modal transportation ideas and products that are tailorable to address under-developed, rural needs and well-developed, urban needs.

Keywords: System of systems, transportation system, standards, architecture, framework, interoperable, integrated.

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1. INTRODUCTION

There is an enduring global need for the efficient transportation of people and goods across land. Worldwide trends such as increasing populations, urbanization, economic uncertainty, climate change, and susceptibility to loss from man-made and natural events are placing stress on existing land-based transportation systems and capabilities. At the same time, the world is moving and functioning faster through the use of the internet, cell phones, computers, and the telecommunications networks that enable the transmission of these digital signals. All of this has placed new challenges, opportunities, and complexity on our capacity to transport ourselves and sustain economic development. Land transportation in the 21st century must address such challenges, take advantage of the opportunities, and reduce or contain the complexity. To achieve these results will require the application of a system of systems approach that unifies existing, diverse transportation modes and systems into a functioning whole, optimizes their operations, and enables future capability growth to respond to national, regional, and local needs.

This paper begins with a system of systems (SoS) description to provide context for three examples of the application of a SoS methodology. The first example describes the formation and attributes of a SoS called a New Mobility Hub using a locally based, small-scale bottom-up process. The second example is a European Commission sustainable transportation report that outlines the steps necessary to develop a future, regional transportation SoS. The US Smart Grid program is cited in the third example to demonstrate the application of a top-down SoS approach that must address existing infrastructure capabilities as new technologies and systems are incorporated to achieve the Smart Grid.

2. SYSTEM OF SYSTEMS DESCRIPTION

A SoS is an expression often used to describe the internet, a defense communications network, a smart electrical grid, or other complex assembly of distributed, stand-alone parts operating as an integrated entity. DeLaurentis and Calloway (2004) have determined that systems of systems generally have three distinguishing traits: physically distributed systems, prime dependency of overall system functionality on the linkages between the distributed systems, and system heterogeneity. According to Sage and Cuppan (2001), modern systems of systems have five common characteristics: operational independence of the individual systems, managerial independence of the systems, geographical distribution, emergent behavior, and evolutionary development. From these descriptions it is possible to converge on a generalized conception of a SoS as comprising a collection of dispersed, independent, current and developing systems that function holistically through SoS defined interfaces and performance parameters to achieve a new level of performance and capability.

Selberg and Austin (2008) go further in defining an evolutionary SoS by adding two principles:

- The complexity of the SoS framework does not grow as constituent systems are added, removed, or replaced.
- The constituent SoS do not need to be re-engineered as other constituent systems are added, removed, or replaced.

These principles may be counterintuitive but for a national transportation system to continue to meet a nation's needs it must be structured to evolve without growing in complexity. System evolution coupled with increased complexity generates the risk of the system collapsing due to its complexity. Similarly, a well structured transportation system with open architectures and defined interfaces will enable constituent system changes without a costly system level redesign.

Using a SoS approach promotes a new way of thinking for solving unprecedented and complex challenges where the interactions of technology, policy and economics influence the system's development and operation. The new thinking must recognize that, unlike traditional system development, a SoS will likely experience greater influence from policy and economics than technology. It also does not mandate specific tools, methods, or practices; instead, the development and maintenance of such systems relies on multiple types and levels of descriptive architectures. These architectures serve the purpose of providing unifying conceptual views as well as identification of interfaces between and among the architectures. The interfaces are the connective points that enable the individual systems to interoperate as a whole system. It is the maintenance of the interfaces that enables the constituent systems to evolve while remaining in and contributing to the integrated whole.

Standards are important, defining elements of the interfaces. According to Maier and Rechtin (2002), standards are network goods that, in economics, are a commodity that increases in value the more it is consumed. In the case of a standard, it increases in value the more widespread its use by products and industries. A standard also provides a degree of uniformity and certainty that fosters system development and performance. In a recent advertisement in the New York Times for its Smarter Planet™ initiative, IBM (2010) wrote, "Importantly, we've learned that our companies, our cities, and our world are complex systems — indeed, systems of systems — that require new things of us as leaders, as workers, and as citizens. ...Global standards, not just technological ones, across all dimensions and at all the interfaces of these complex systems. ...A smarter planet will require a profound shift in management and governance toward far more collaborative approaches." As IBM notes, standards are not solely technical in nature. Many standards come from standard-setting organizations such as the International Standards Organization (ISO), but they can also take the form of best practices and design guides that, through widespread application, become de facto standards. The de facto standards become more evident as guiding solutions when applied to local situations that are more directly influenced by social, political, and cultural effects. In applying standards to a system it is also important to identify the areas where standards do not exist and the existing standards that require modification.

Standards must also be managed over the life of the system to ensure they continue to be enablers for system interoperability and performance. Standards that are locally imposed will be the easiest to manage over time whereas more broadly used standards will require existing or new standards-governing bodies to add, modify, or delete standards to address evolving requirements and technologies.

In the context of transportation, a SoS approach has the flexibility to be used at the macro global, regional, and national levels, and at the micro local, neighborhood levels. It can be applied to relatively small-scale, grass roots, bottom-up initiatives as well as large-scale, complex, top-down solutions with strong governmental involvement or strong market-driven emphasis. A bottom-up approach relying on local, limited resources to identify the existing components of a here-to-fore unrecognized SoS can begin by simply mapping how the existing independent components intersect and interoperate to form a higher-level SoS. This newly identified, local SoS when combined with other local systems will itself become a constituent system or building block in a larger, regional or national transportation SoS. In essence, a national level transportation system then becomes a system of smaller systems of systems that interoperate through shared architectural frameworks, interfaces, and standards.

3. APPLICATION TO NEW MOBILITY HUBS

An example of a bottom-up, collaborative initiative that informs and engenders a complementary top down SoS approach is the Sustainable Mobility and Accessibility Research and Transportation (SMART) program at the University of Michigan.[1] SMART is executing a series of pilot projects for its New Mobility Hub concept working with communities around the world to link existing service, product, technology, and design options and innovations together to create previously unrecognized transportation solutions. New Mobility Hubs use the bottom-up approach to create neighborhood up to metropolitan area level systems of systems. While each hub is geographically dispersed from other hubs, it is also comprised of geographically dispersed, independent transportation and supporting systems such as bus stops, taxi stands, ATMs, and WiFi hotspots that bring new capabilities and opportunities for people and businesses. Definition of the functioning components of the New Mobility Hub network continues with the identification of interfaces and the application of standards that provide the stable, defining measures that governments, industry, entrepreneurs, and users can utilize to create new open, plug-and-play products and services:

> "New Mobility hub networks exemplify seamless door to door solutions that support a personalized, customized, connected portfolio of transportation services, products, technologies and design, much like our personalized tele-communications portfolios that connect i-Pod, laptop, desktop, Google, cell phone, etc.. A New Mobility Hub network is a series of ubiquitous hubs, or transfer points around a city where connections can be made easily from one mode or service to another seamlessly. For example one might arrive at a vibrant hub on a bus or train having reserved a car share vehicle with one's cell phone-based traveler information and fare payment technology. Quickly and conveniently one can gain access to the car-share vehicle at the hub, transfer to the car share vehicle as needed, and drop it off at another hub. At that subsequent hub, one might pick up a bike, share vehicle or decide to stay at the hub and use the satellite office, or pick the children up from daycare, or browse in a bookstore".

Finally, SMART's New Mobility Hub networks are examples of applying the SoS methodology to previously disassociated, yet geographically proximate clusters of transit systems, multiple transportation modes, fare payment methods, communication networks, businesses, and information resources to make communities aware of the existing assets available to them. SMART has used a simple exercise of bringing a local area's transportation stakeholders together around a map of the community to identify where existing transportation and communication systems are located. From this exercise the community creates an initial version of a community transportation and communication SoS that had not been previously seen. This initial version provides the basis for a beginning system conceptual framework that establishes a common understanding of the new system and identifies the existence of potential interfaces between the constituent systems. SMART's New Mobility Hubs demonstrate that the first gains from applying a SoS process are the identification and integration of the existing capabilities into a larger SoS that provides new functionality to the community.

4. INSIGHTS FROM EUROPEAN TRANSPORTATION

At the other end of the spectrum, the European Commission's 2009 report, A Sustainable Future for Transport, is an example of a top-down, regional plan aimed at setting a strategy for the future application of a SoS. In its report, the Commission describes a compelling need for a technological shift towards lower and zero emission vehicles and for the development of alternative means of sustainable transport. To do this, the report identifies the necessity of having supporting framework conditions in place to introduce new commercial technologies without an appearance of picking winners. The framework conditions include open standards, ensuring interoperability through established interfaces, defining the supporting legal and regulatory foundations, and the promotion of best practices. The report, in particular, emphasizes the importance of setting standards.

The most important policy instrument will probably be the standard setting. The transition to a new and integrated transport system will only be quick and successful if open standards and norms for new infrastructure and vehicles and other necessary devices and equipment are introduced. The standard setting

1 University of Michigan. SMART. 2010-07-15. URL:http://www.um-smart.org/. Accessed: 2010-07-15. (Archived by WebCite® at http://www.webcitation.org/5rEoZKt5x)

should aim at interoperable, safe, and user-friendly equipment. This is not only important for the internal market, but also to foster European standards on an international scale. The development of intelligent transport systems or alternative vehicle propulsion systems could provide a success comparable to that of GSM technology. Policymakers must, however, ensure that the standard setting process avoids the introduction of barriers to market entry and to the development of alternative technologies (European Commission 2009).

5. THE SMART GRID EXAMPLE

Practical application of the SoS methodology to any level of transportation system will require an assessment of existing capabilities and then a forecast of the new capabilities and technologies that are options for future integration. Though not a transportation system, the US National Institute of Standards and Technology (NIST) is executing a similar task for the Smart Grid. In 2007, NIST was assigned the responsibility to coordinate the development of a framework to achieve the interoperability of the emerging Smart Grid devices and systems. For the Smart Grid, the interoperability framework must accommodate traditional power generation and distribution means and also facilitate the incorporation of new, innovative technologies.

The interoperability framework includes a conceptual reference model that provides the common, unifying understanding and view of the Smart Grid for the multiple Smart Grid stakeholders. The conceptual reference model captures the characteristics, uses, behavior, and other elements of the Smart Grid. Developing the conceptual model requires the inputs and consensus of the Smart Grid stakeholders to identify the Grid's major building blocks and their interrelationships. The building blocks and their interrelationships lead to the identification of interfaces and standards to ensure interoperability and performance. As shown in Figure 1, the conceptual model was divided into seven domains. Each domain, with its associated sub-domains, captures all of the Smart Grid actors and applications.

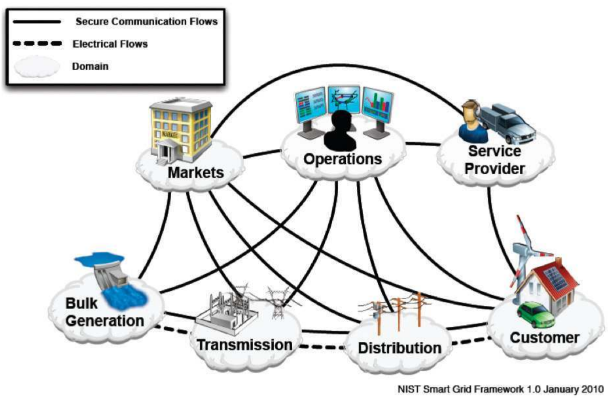

Figure 1. Smart Grid Conceptual Reference Model.
Source: NIST Framework and Roadmap for Smart Grid Interoperability Standards January 2010.

With the Smart Grid's building blocks, or domains, created and their interrelationships established, the next step for the framework was the assignment of standards, the identification of missing standards, and those requiring modification. Sound interoperability standards are needed to ensure that sizable public and private sector technology investments are not stranded. Such standards enable diverse systems and their components to work together and to securely exchange meaningful, actionable information (NIST 2010). For each standard requiring modification or creation, an action plan was developed to accomplish the task.

A final note on the NIST Smart Grid framework is the success to this point of the process used to generate the framework. NIST recognized that developing the Smart Grid required the participation of stakeholders who represented the current electrical grid, stakeholders who represented the new Smart Grid components, and stakeholders who represented groups who had not previously been identified as stakeholders. To bring such a diverse collection together necessitated the engagement of a broad spectrum of views that could be properly heard only in open and public proceedings. NIST held three public workshops that attracted over 1500 people. NIST also recognized that it was dealing with a very complex problem with numerous parts that could not simply be described by an all-encompassing system of system-level architecture. Instead, they chose to use the framework with its conceptual reference model as the means for helping the stakeholders envision and understand the Smart Grid interoperability needs. The conceptual reference model enabled the creation of a set of priority actions plans to address specific issues in addition to furthering detailed characterization and development of the individual domains.

6. CONCLUSION

Looking to the future, intelligent transportation systems (ITS) such as IntelliDrive™ and HAVEit™ are in various stages of development around the world. Combining new vehicle capabilities with communication networks that enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, ITS is seen by many as part of a future solution set that addresses the desires for improved vehicle occupant and pedestrian safety, and reduced traffic congestion. In the context of an evolving national, or regional transportation system, ITS is one part of the larger, top-level system along with other constituent systems such as high speed rail and public transit that require a Smart Grid-like conceptual framework to show the interdependent relationships of the components. In a New Mobility Hub, ITS will be one component of a diverse community of transportation modes, supporting businesses, information and traffic management, and revenue collection and management services that combine into a SoS that brings new opportunities to the New Mobility Hub's planners and users. As existing transportation systems and related services become integrated with new systems such as a Smart Grid that provides energy for plug-in electric vehicles or an app-based mobile computing environment, it will be the challenge for all levels of the public and private sectors to work together in new and expanded ways to achieve a seamless evolution of capability and operation. As nations try to balance concerns for stimulating weak economic growth against rising national debt loads it is clear that improved transportation must develop new public/private relationships and solutions that open previously untapped individual and entrepreneurial creativity akin to the hundreds of thousands of smart phone applications. Longterm sustainability requires a dependable yet adaptable framework of standards, best practices, and specifications that continually enable innovation to meet known and unknown circumstances. The global transportation picture will not become simpler over time, yet it will become more important to our daily lives and livelihoods.

The SoS approach is a flexible, practical, and ready-to-go method that fosters the critical tailoring and adaptation necessary to meet a particular project's challenges, regardless of whether it is a new, top down, Smart Grid or a bottom up, New Mobility Hub. Going forward in the 21st century, the world's needs for transportation have many shared attributes yet each situation or system is unique. Able to integrate diverse systems horizontally and from top to bottom, a SoS approach provides a core set of tools for effectively conceptualizing, organizing, integrating, and communicating solutions to meet those transportation needs.

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