Observing the health of the ecosystem supporting the emerging connected vehicle system of systems

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Abstract. *A healthy ecosystem creates new features and products and attracts new participants. In this study a set of accepted criteria for a healthy software ecosystem is investigated as to whether those criteria adequately address the health of the more complex ecosystem supporting a system-of-systems. The system-of-systems composed of intelligent traffic control infrastructure, connected vehicles, and people is supported by an ecosystem that is very healthy due to government and industry support. We use this socio-technical ecosystem as the testbed for ecosystem health metrics. This preliminary work will guide a more in-depth study considering other criteria.*

1. Introduction

Today's vehicles are increasingly connected to intelligent traffic infrastructure, the Internet, and to each other. In many cases these connections are the result of an integration of systems that are independently owned and operated. Smart phones are connected via Bluetooth radio to the navigation system of the car. New opportunities are rapidly emerging. DSRC radios will provide vehicle to vehicle (V2V) coordination for platooning sets of vehicles for fuel efficient travel effectively creating a new system. This evolution is integrating the efforts from a variety of communities in new ways. The resulting ecosystem is an interaction of the ecosystems surrounding these diverse domains.

The connected vehicle traffic control system is a system-of-systems (SoS) according to the definition given by Maier [Maier 1998]. A standalone system joins the SoS when it comes within radio range or connects through a network, and then leaves the system as it moves away, or disconnects, from the other elements of the system. These independently owned and operated systems must interoperate for the traffic control system to achieve its purpose, i.e. the safe and efficient management of traffic flow.

As described in our previous work, each of the standalone systems composed into the system of systems is nurtured by its own socio-technical ecosystem [Amorim et al. 2014]. A socio-technical ecosystem gives equal weight to the people and the technical issues involved in creating and sustaining a product [Feiler et al. 2006]. The ecosystem consists of the organizations that cooperate and compete with the organization producing the system. The actions of the ecosystem are also the result of actions and culture of the people working in those organizations.

The SoS resulting from the composition of the standalone systems is likewise supported by an ecosystem. In previous work we described how the ecosystems, from which the systems in the SoS come, could be used to guide the assembly of the SoS [Klein and McGregor 2013]. The SoS can be successful only if its constituent systems have business strategies and technical roadmaps that are sufficiently aligned. The rest of this paper will refer to the set of constituent systems that are integrated to form the SoS and to the constituent ecosystems that interact to form the ecosystem of the SoS.

A prime concern, as the SoS ecosystem is being formed, is whether the ecosystem is healthy and will remain so. Our hypothesis is that the health of this new ecosystem is related to the health of the ecosystems containing the constituent systems. In this short paper we will expand on what that means, give examples from the connected vehicle domain, and describe challenges to continue this work.

Several models for a SoS are possible. Due to space limitations, we will address only one: a platform-based SoS, in which all of the systems are developed by independent but collaborating organizations [Klein and McGregor 2013]. The Maier criteria call for operational and managerial independence of each system in the SoS. In the platform-based approach, systems are managerially and operationally independent but are designed on a shared platform of common services. The shared platform provides services needed by two or more of the constituent systems.

The rest of this paper is structured as follows: section 2 defines what we mean by the health of a SoS ecosystem; section 3 expands on the connected vehicle example; section 4 describes some challenges to keeping the SoS ecosystem's health;and finally section 5 presents conclusions and future work.

2. Health of the SoS Ecosystem

The organizations in the ecosystem surrounding a SoS are responsible for assembling the SoS and for maintaining it in the face of continually evolving constituent systems. There is a dependency between the SoS ecosystem and those of the standalone systems. The SoS must anticipate updates to the constituent systems and will feedback bug reports and change requests to the appropriate ecosystems. Since the ecosystem strategy is intended to contribute to the health of an organization employing the strategy, we are interested in the health of this new ecosystem and the confounding effects, if any, of these inter-ecosystem dependencies. At a minimum we can use the same metrics by which we evaluate the health of any software ecosystem: Productivity, Niche Creation, and Robustness [Iansiti and Levien 2000]. In a SoS's context these may take on somewhat different meanings.

The productivity of the ecosystem surrounding a SoS is tied to the productivity of the ecosystems surrounding the constituent systems. Consider a request for a new feature in the SoS. The SoS organization is responsible for parsing the change request and determining how the new feature would be provided. This will often result in change requests being created for several of the constituent systems. Some of the change requests will be directed at the platform team and others at the constituent systems. In both cases there are dependencies among these changes. That is, some changes are needed before other changes can be created. The SoS's change control board identifies the dependencies and addresses them in submitting the requests to the other organizations.

The SoS ecosystem must encourage new collaborators with new ideas to establish new products and new markets. Much of this new activity will occur in niches within existing markets. New business models, new technologies, and changing circumstances such as aging populations lead to new ideas. Typically a SoS ecosystem is not as agile as a single system but niche creation actually often begins in the ecosystem surrounding one of the constituent systems. If the new niche is first recognized in an individual system's ecosystem, the market's reception can be judged with less risk than at the SoS level niche.

SoS ecosystems must be robust even with organizations entering and leaving the ecosystem, priorities changing, and popularity trending up and down. One approach to this is redundancy in suppliers - multiple ways of providing a specific feature. In the SoS ecosystem with relationships to several different ecosystems, it is often possible to identify multiple sources. Another approach is to reduce the cost of entry into the new market. A platform-based SoS will be more robust than a single system ecosystem since to enter a platform-based ecosystem an organization only needs to build from the platform up rather than from scratch.

Our initial investigation identified an additional health characteristic for a SoS ecosystem - cohesiveness. The constituent systems in an SoS must fit well together. Cohesiveness can be seen in how much glue code is needed between the systems within the ecosystem. Over time the individual systems evolve and may require additional glue code to interoperate. A cohesive ecosystem has minimum amount of glue code.

3. Example

Connecting vehicles to the traffic control infrastructure and to other vehicles holds the promise of significant improvements in safety and fuel efficiency. The United States Department of Transportation (DoT) has created the Connected Vehicle Reference Implementation Architecture (CVRIA). This reference architecture is the blueprint for a system of systems for connected vehicles.

A connected vehicle has wireless connections to other devices. It may use a cellular, Bluetooth, DSRC[1], WiFi, or other type of communication protocol. All of the onboard devices interface with various services in the vehicle and connect to different types of servers to which the device can connect at a point in time. At any instant in time the SoS is composed of interacting traffic infrastructure, vehicles, and people.

Productivity - The CVRIA ecosystem is currently very productive. There is a large number of infrastructure products designed to be compatible with the CVRIA. The DoT recently had a funding program related to CVRIA compliant products and this is encouraging further development.

Niche creation - The CVRIA ecosystem is creating a number of new research initiatives in the area of safety of connected vehicles. Several of the V2V technologies are creating new opportunities.

Robustness - Government funding as well as support from a number of original equipment manufacturers makes the connected vehicle traffic ecosystem very robust. The promise of greatly reduced accidents is attracting much participation in the development

[1]Dedicated Short-Range Communications

of products that will interoperate within the ecosystem. Government ownership of much of the traffic infrastructure ensures that the ecosystem will remain robust further encouraging activity.

Cohesiveness - Existing traffic regulations, constraints described in the CVRIA result, and Society for Automotive Engineers (SAE) standards ensure the cohesiveness of this ecosystem.

4. Challenges

We have observed that there are several challenges to achieving adequate health of the constituent ecosystems:

Community alignment - The challenge is the management of different rules and behavior standards among the groups in the individual ecosystem communities. The rules of a single ecosystem should be aligned to avoid a collision of interest among the members of the other communities.

Management of multiple markets - The ecosystems should support the SoS and other applications and be present in different markets inside and outside the SoS. The directions of the SoS and ecosystems should be synchronized to avoid the withdrawal of participant systems.

Architectural decisions - For a platform-based SoS, architectural decisions must be separated into those that support all applications on the system-of-systems and those that support only those applications within a single ecosystem. Besides, another challenge is to manage all dependencies among these projects to satisfy both niche markets.

5. Conclusions and Future work

Our initial investigation of ecosystems that support SoS has identified one new characteristic of ecosystem health - cohesiveness. This characteristic reflects the integrative nature of the SoS and its ecosystem. Our future work will include additional literature searches and interviews with engineers designing SoS for recurring use of specific criteria for evaluating the health of the ecosystems supporting a SoS.

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