Military Operations Research Society

Joint Framework for Measuring C2 Effectiveness

January 23-26, 2012

Working Group 3:

Operations Analysis for Systems of System within a Networked C2 Context

Introduction, Purpose, and Approach

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Outline

- Introductions
- Approach
- Purpose
- Objectives
- Schedule
- Discussion Starters
  - Measurement
  - Systems of Systems
  - Command and Control
  - Methods, Tools,
  - Examples

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Introductions: Working Group Composition

- Clyde Smithson (JHU/APL) Chair
- Marjorie Greene (CNA) Co-Chair
- John Foulkes (xxx)
- David Koewler (HQDA)
- Mike Kwinn (xxx)
- Tim Madgett (AFAMS)
- Chad Ohlandt (Rand Corporation)
- Joe Quartararo (AFMC 46 TS)
- Mary Ray (TRADOC Analysis Center)
- Thomas Reid (DTRA)
- NormanYarbrough (OSD)

Working Group Approach

- **Idealize**: define an ideal future state
- **Diagnose**: identify the key issues
- **Explore**: brainstorm creative strategies for addressing the issues identified
- **Assess and analyze**: evaluate potential strategies
- **Story**: wrap the resulting solution into a story that wins the interest and support of the key stakeholders needed to bring the idea to fruition.[1]

1. Kaihan Krippendorff, Unlocking Innovation: Out-think Your Competitions. www.kaihan.net/Unlocking_innovation.pdf

WG 3 Schedule

- Tuesday
  - 1010-1130 Session 1 – Introduction, Approach, Objectives
  - 1300-1630 Session 2 – System of Systems, Measurement, C2 Framework (Conceptual Model), OR (& Other) Methods
- Wednesday
  - 0845-1200 Session 3 – C2 Framework, OR Methods MOOs, MOEs, MOPs Development Case Study
  - 1300-1630 Session 4 – Findings, Recommendations, Conclusions
- Thursday
  - 0800-1200 Session 5 – Outbrief Preparation
  - 1420-1450 WG 3 Outbrief

Purpose

- Because networked C2 systems are actually “systems of systems” this working group will examine the difficulties of applying operations research techniques to them in this context. Networked systems exhibit behavior that is complex and defies the usual techniques of measuring effectiveness at discrete points. This working group will explore the correct approaches for measuring and assessing network behaviors and the effectiveness of the network.

Objectives

- Objective 1: Understand the impact of the application of traditional operational research techniques to networked C2 systems.
- Objective 2: Develop inputs to the C2 Metrics Framework for networked C2 systems and "systems of systems" to measure and assess network behaviors.
- Objective 3: Identify and categorize families of C2 measures of effectiveness useful for networked C2 systems.

- Task 1: Challenge these objectives

C2 Network Effectiveness Framework

1. **Mission and Context definition**
2. **What is the minimum data content needed to produce desired behavior? What is the optimal (locally optimal, local sub-optimization to achieve SOS goals) data content? Might be akin to fidelity (scale and scope) measures to be defined for the network.**
3. **Cost measures including cost and time to implement the solution (for example, a basic rule-of-thumb I use for development, integration, fielding of a new TADIL-J message is on the order of $1B). Acceptable risk. How these factors would form a tradespace. Relating effectiveness measures back to WG – 1 & 2.**
4. **Includes concepts such as:**
   - **System/network boundaries – explicit & derived assumptions, entities & interactions (nodes & links)**
   - **System/network behaviors – entities, events, states, functions, time**
   - **System/network forms – architecture, bandwidth, latency, error, etc.**
5. **Other topics**
   - **Network permeability, secure networks; relate to risk**
   - **Emergent Behavior (at multiple levels)**

C2 Network Effectiveness Paradigm

- **Commander's Intent**
- **Mission Outcome/Success**
- **C2 Network Layers**
  - **Physical**
  - **Information**
  - **Cognitive**

C2 Network Paradigms

1. **Quality of Information (QOI), Quality of Service (QoS) metrics – that describe the impact to the behavior of the SOS; especially in the context of outcomes I think taking a look at something like on OSI 7-layer model as a way to categorize metrics. My sense is that most of the discussion would be in the Host Layer (Application, Presentation, Session, Transport) to describe behavior; however, the impact of lower layers will be important as I think there may be metrics associated with, for example, bandwidth (which may in turn drive media – fiber, RF, IR, EO, etc.) as low as at the Physical Layer.**
2. **Cloud Computing Paradigm (Apps/Mission, Methods/Tools, Transport/Network)**
3. **A method to relate effectiveness metrics back to cost (and possibly schedule) and risk.**

Tutorials & Reading

- **Tutorials**
  - **Day 1 Tutorials (*TBD*)**
  - **Metrics 101[Condensed Edition] & 201- R. W. Eberth**
- **Reading**
  - **NATO Code of Best Practices for C2 Assessment**
  - **Command & Control: The Sociotechnical Perspective**
  - **Formulating Measures of Effectiveness – N. Sproles**
  - **Coming to Grips with Measures of Effectiveness – N. Sproles**
  - **The Difficult Problem of Establishing Measures of Effectiveness for Command and Control: A Systems Engineering Perspective – N. Sproles**
  - **An Approach to Simulation Effectiveness – D. Goncalves *(this last is provided as a thought exercise and example; can a similar technique be applied to describing C2 Network Effectiveness?)***

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Operations Analysis for Systems of System within a Networked C2 Context

DISCUSSION STARTERS

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Operations Analysis for Systems of System within a Networked C2 Context

MEASUREMENT

Measures

- Measures of Outcome
  - Commander’s Intent
  - Mission Success
- Measures of Effectiveness
  - Effectiveness, Efficiency
  - Quality of Information
  - Cost, Schedule, Risk
- Measures of Performance
  - Quality of Service
  - Network Metrics

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Operations Analysis for Systems of System within a Networked C2 Context

SYSTEMS OF SYSTEMS

Systems of Systems Definition (DoD SE Guide for SoS)

- **System**
  - **A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole [JP 1-02 & JP 3-0].**
- **Capability**
  - **A capability is the ability to achieve a desired effect under specified standards and conditions through combinations of ways and means to perform a set of tasks [CJCS, 2007(2)].**
- **System of Systems**
  - **An SoS is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [DoD, 2004(1)].** ***Both individual systems and SoS conform to the accepted definition of a system in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS.***

Describing Systems, Systems of Systems, Complex Systems

The nature of large complex system development is contrasted with that for a traditional system. In the traditional case a legacy system capability may be able to be swapped out entirely by a new system. This case tends to prioritize in order of technical, operational, economic, and political (TOEP) merits. For a SoS it is much more complex to introduce new/improved capability without affecting overall capability due to the number of systems, complex interactions between systems, their unique capabilities, and the different development/acquisition organizations. Much more must be balanced and negotiated across the SoS so priorities tend to align to political, operational, economic, and technical (POET) merits. One can argue the relative positions of operational and economic in this case.

Because of the complexity of the socio-technical system involved it is critical to first frame the effectiveness referent and the problem context, especially across the various social entities to determine driving factors for each and, hopefully, establish common problem characteristics across multiple organizations. These common characteristics will serve as the basis from which to formulate measures of merit for the SoS Effectiveness & Performance assessment. The measures of merit should be of both the qualitative and quantitative type, and be able to tolerate a certain level of ambiguity across the SoS.

The POET nature of the SoS indicates that the development, testing and integration, and assessment of the system cannot strictly be addressed through traditional methods alone, such as operations research, systems analysis, or traditional system engineering. Although these form a backbone for addressing the SoS problem, especially when viewing the individual systems/sub-systems/components forming the SoS. The wide Stakeholder base, multi-mission nature of some parts of the SoS, and the open nature of the of most C2 systems(with vague and permeable system boundaries) means that there may be no single simple view to which the system can be reduced.

DoD SE Guide for Systems of Systems

- **In DoD and elsewhere, SoS can take different forms. Based on a recognized taxonomy of SoS, there are four types of SoS which are found in the DoD today [Maier,1998; Dahmann, 2008].**
  - **Virtual.** **Virtual SoS lack a central management authority and a centrally agreed upon purpose for the system-of-systems. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely upon relatively invisible mechanisms to maintain it.**
  - **Collaborative.** **In collaborative SoS the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.**
  - **Acknowledged.** **Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.**
  - **Directed.** **Directed SoS are those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.**

Maier, M. (1998); "Architecting Principles for Systems-of-Systems"; Systems Engineering, Vol. 1, No. 4 (pp 267-284).

Dahmann, Judith and Kristen Baldwin, (2008), "Understanding the Current State of US Defense Systems of Systems and the Implications for Systems Engineering", Montreal, Canada: IEEE Systems Conference, 7-10 April.

Systems of Systems Management & Oversight and Operational Environment

Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Management & Oversight				
Stakeholder Involvement	Stakeholders at both system level and SoS levels (including the system owners), with competing interests and priorities; in some cases, the system stakeholder has no vested interest in the SoS; all stakeholders may not be recognized.	A virtual SoS has no centrally established purposes but rather the purpose expresses itself as the collective actions of the individual systems.	Stakeholders negotiate among themselves to establish a common purpose. The SoS is built to this purpose and the individual systems negotiate among themselves to determine which part of this responsibility each fulfills. Central players often establish the ground rules by which other players participate.	A central SoS authority usually establishes the purpose to be achieved by the SoS. The SoS is built to this purpose and the individual systems are generally directed by the central authority.
Governance	Added levels of complexity due to management and funding for both the SoS and individual systems; SoS does not have authority over all the systems.	No central body controls the purpose or management of the SoS or individual systems. Governance may emerge from politics or policies agreed to by stakeholders but none is compelled to comply.	In collaborative SoS there is no central authority with the power to enforce a particular SoS purpose. A central authority may establish purposes, standards, etc., which are usually complied with, but does not have authority to enforce them.	Individual systems are governed by membership to a common SoS command structure which usually includes a central governing authority.
Operational Environment				
Operational Focus	Called upon to meet a set of operational objectives using systems whose objectives may or may not align with the SoS objectives.	Individual systems are operated independently. Operation of the SoS is complex because there is no centrally directed/controlled purpose. Participation by systems is voluntary and they often have conflicting purposes which they will try to attain simultaneously with other systems.	Collaborative SoS differs from directed SoS in that a central authority is not able to enforce particular operation of the system. Systems collaborate of their own will to achieve a central purpose; however, from time to time SoS operational needs are subjugated to the needs of a particular system.	The systems are connected by command and control structures. The SoS directs the operation of individual systems to achieve the SoS purpose (a centralized control authority). Systems are usually allowed operational independence to deal with local situations.

*Table adapted & Acknowledged SoS definitions from DoD SE Guide for SoS; others defined by this author.

Systems of Systems Implementation

Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Implementation				
Acquisition	Added complexity due to multiple system lifecycles across acquisition programs, involving legacy systems, systems under development, new developments, and technology insertion; Typically have stated capability objectives upfront which may need to be translated into formal requirements.	Component systems are acquired independently without regard to other systems, except in the context that another system may perform a beneficial function for that system (usually at little or no cost) and dependably.	Systems negotiate among themselves to determine how SoS objectives are to be met and which system is to provide which SoS capability. Agreements are made between central players to form a common acquisition strategy. This can be seen as negotiated "political" objective as opposed to direction by central authority.	Individual systems are acquired through different program offices and operated separately; however, there is a central authority directing, coordinating, and balancing the various program offices. Systems may be custom built to meet the needs of the SoS.
Test & Evaluation	Testing is more challenging due to the difficulty of synchronizing across multiple systems' life cycles; given the complexity of all the moving parts and potential for unintended consequences.	SoS testing generally occurs on an ad hoc basis. Individual systems test themselves. Testing at the SoS level is confined to aspects of the SoS at that level that affect the function and purpose of individual systems. In other words a system only tests what is important to itself at the SoS level, if any SoS testing is conducted at all.	SoS testing is established by coordination and negotiation between the central SoS players. Testing tends to change over time as the SoS purpose evolves. For a directed SoS the testing tends to be directed from top down whereas for virtual SoS it springs up organically. T&E for a collaborative system comes from a middle ground in which the central players establish goals that are tested by the entire SoS.	Testing occurs at multiple levels but is directed from the SoS level At the SoS level testing is directed to evaluate the central purpose of the SoS. Testing may occur with the entire SoS or portions of it. Additionally, testing occurs at the system level to establish that the system meets its individual requirements, including those supporting the system purpose.

*Table adapted & Acknowledged SoS definitions from DoD SE Guide for SoS; others defined by this author.

Systems of Systems Engineering & Design Considerations

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Aspect of Environment	Acknowledged SoS*	Virtual SoS	Collaborative SoS	Directed SoS
Engineering & Design Considerations				
Boundaries and Interfaces	Focus on identifying the systems that contribute to the SoS objectives and enabling the flow of data, control and functionality across the SoS while balancing needs of the systems.	Boundaries and interfaces evolve through adaptation and survival – successful standards live and are extended upon while others die out. Forces other than the technical merits of these may determine survival (e.g., VHS vs. Betamax). Systems choose to use or not use these at their own discretion. A standard may be created by an individual system, and then be adopted by others.	Certain systems rise to be central players at the SoS level. These systems usually reach agreement on what the interface standards are and what services to provide. They usually create common standards for use by the entire SoS but do not enforce them (except by operationally excluding other systems that do not conform).	Interfaces are seen as a key integrating factor for the SoS. A central authority establishes the interface requirements, with input from the component systems. Similarly, the central authority establishes the boundaries between systems.
Performance & Behavior	Performance across the SoS that satisfies SoS user capability needs while balancing needs of the systems.	The performance of the SoS is not directed, but rather is an emergent behavior. There are no established SoS performance requirements. Individual systems optimize to perform best for their own ends (i.e., best ROI at the system level) and SoS performance derives from that.	Like the virtual SoS, there are no minimum SoS performance requirements enforced by a central authority. Rather, the constituent systems agree to a set of mutual performance goals and behaviors which evolve over time. Individual systems may choose to sub optimize to benefit the SoS.	All constituent systems must met minimum performance requirements to satisfy SoS capability requirements. Individual systems may be operated sub optimally to meet SoS performance requirement. Generally, individual system performance is secondary to SoS performance.

*Table adapted & Acknowledged SoS definitions from DoD SE Guide for SoS; others defined by this author.

Typical Systems of Systems Characteristics

Characteristic	Description
Operational Independence	The constituent Systems of the SoS are often able to, and do, operate independently. Subsets of the SoS can perform SoS missions in the absence of the rest of the system.
Managerial Independence	Constituent Systems of the SoS are successfully developed and integrated independently outside the SoS.
Evolutionary Development	The constituent Systems and SoS are built over many years and capabilities are added incrementally.
Emergent Behavior	The full spectrum of layered SoS can only be provided by all constituent Systems operating together.
Geographic Distribution	Constituent Systems of the SoS are distributed world-wide, may be mobile, and communicate via data networks.

Attributes of System Complexity (1 of 2)

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Problem Characteristic	Simple	Complex	Your System	Complexity Rationale
Number of Elements	Small	Large	?	• **Internal Social:** Multiple competing Directorates, Services/Program Offices, Contractors, UARCs/FFRDCs, Warfighters • **Internal Technical:** Large number of systems, sub-systems, etc. • **External Social:** Congress, POTUS, DOT&E, Services, Warfighters • **External Technical:** Other services necessary, such as communications, not under system's control
Interactions	Few	Many	?	• **Technical:** The SoS interacts between Systems and externals through numerous links and interfaces • **Social:** SoS interactions occur across multiple Design, Development, VV&A, Test, Operational teams within Service, Contractors, Program Offices
Predetermined Attributes	Yes	No	?	• Wide variety of Systems • Multiple disparate stakeholders • SoS organization changes – over time based on operational SoS and Systems • System boundaries difficult to define – especially with regard to the operator being a part of the system or external to it.

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Attributes of System Complexity (2 of 2)

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Problem Characteristic	Simple	Complex	Your System	Complexity Rationale
Interaction Organization	Highly Organized	Loosely Organized	?	• Many activities are centrally organized but executed locally or distributed. • Systems, Sub-systems, Service, Operators are differently organized.
Laws Governing Behavior	Well Defined	Probabilistic	?	• Degree to which the behavior of the SoS is predictable – emergent behavior
System Evolution Over Time	Does Not Evolve	Evolves	?	• Overlapping complex planned SoS evolution at System and Sub-system levels over different time frames.
Subsystems Pursue Own Goals	No	Yes (Purposeful)	?	• Programs and services are driven toward meeting the goals of their own systems • Many Systems are complex in their own rights and have missions other than that of the SoS.
Systems Affected by Behavioral Influences	No	Yes	?	• Different service paradigms operating in "joint" world • Differences between R&D, Developers, Integrators, Testers, Operators
Predominantly Closed or Open to the Environment	Largely Closed	Largely Open	?	• Primary purpose of the system is to address external factors • Subject to environment • Depends upon external services (such as comms) to accomplish mission

Wicked Problems and Social Complexity*

1. **You don't understand the problem until you have developed a solution.**
   - Every SoS "solution" exposes new/different aspects of the problem.
   - The problem is ill-structured with evolving interrelated issues and constraints.
   - Different stakeholders have different viewpoints.
2. **Wicked problems have no stopping rule.**
   - Problem solving is usually limited by resources rather than discovery of an optimal solution.
3. **Solutions to wicked problems are not right or wrong.**
   - There is no optimal solution, but "better or worse", "good enough or not good enough."
4. **Every wicked problem is essentially unique and novel.**
   - Many factors and conditions are embedded in a dynamic socio-technical context.
5. **Every solution to a wicked problem is a "one-shot operation."**
   - You cannot build a SoS just to see how it works.
   - But you can't learn about the problem without trying solutions.
6. **Wicked problems have no given alternative solutions.**
   - There may be no solutions, or there may be many solutions.
   - Creativity in selecting solutions and judging which are valid is critical.

*Jeff Conklin, *Wicked Problems & Social Complexity*, http://www.cognexus.org/wpf/wickedproblems.pdf

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COMMAND AND CONTROL

Working Group 3:

Operations Analysis for Systems of System within a Networked C2 Context

DENVER INTELLIGENT TRAFFIC SYSTEM

Denver-Boulder, Colorado Metro Intelligent Transportation System (ITS)

- A case study of a civilian command and control system:
  - **Briefly, the concept of operations for the ITS is to Detect, Surveil, Monitor, and Assess arterial and freeway roadways for traffic conditions, road conditions, and incidents. This information is used to provide control of the roadway such as changing road rules (speed, direction, etc.) and provide information to other system elements. In addition the ITS provides and maintains an electronic fee collection system for road and transit usage and provides timely and useful information to travelers. Additionally the ITS manages a transit system, manages any roadway incidents (by changing road rules and dispatching resources as needed) and links to the EMS system to respond to emergency situations. The ITS performs some of its functions autonomously and some under operator control. The ITS links to other information systems and communications networks to receive and distribute pertinent information.**

High Level System Descriptions

- System Diagrams
  - Boundary Diagram for the Denver-Boulder ITS.
  - UML Class Diagrams for the Denver-Boulder ITS and represent the most current information from 2006 [ref. 8]. High level interfaces are only shown in first for clarity. Second figure illustrates the class structure with attributes and operations of the various classes. It is recognized that many similar attributes and operations appear across the classes which could lead to further refinement producing common use sub-classes. DisseminateInfo is an example where a common method using common message sets could be applied.
- System MOEs and MOPs
  - The table outlines the ITS MOEs and MOPs. The ITS System MOEs are both quantitative (e.g., miles/% of roadway), and qualitative (e.g., is a capability present). The ITS MOPs include "ilities" for all components such as, Mean-Time-To-Failure, Mean-Time-To-Repair, Reliability, Availability, Maintainability, etc. so these are not included in the Table.

Denver-Boulder ITS Boundary Diagram

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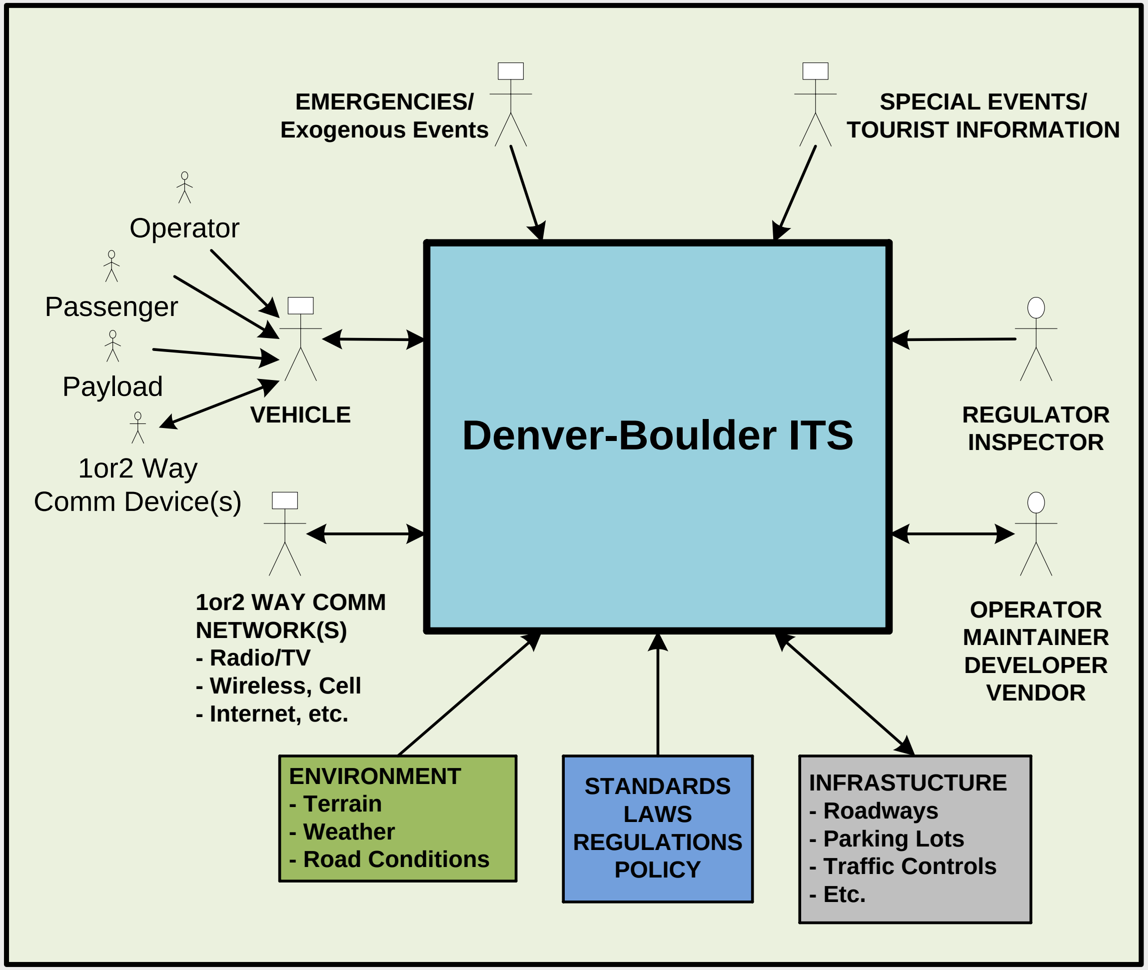
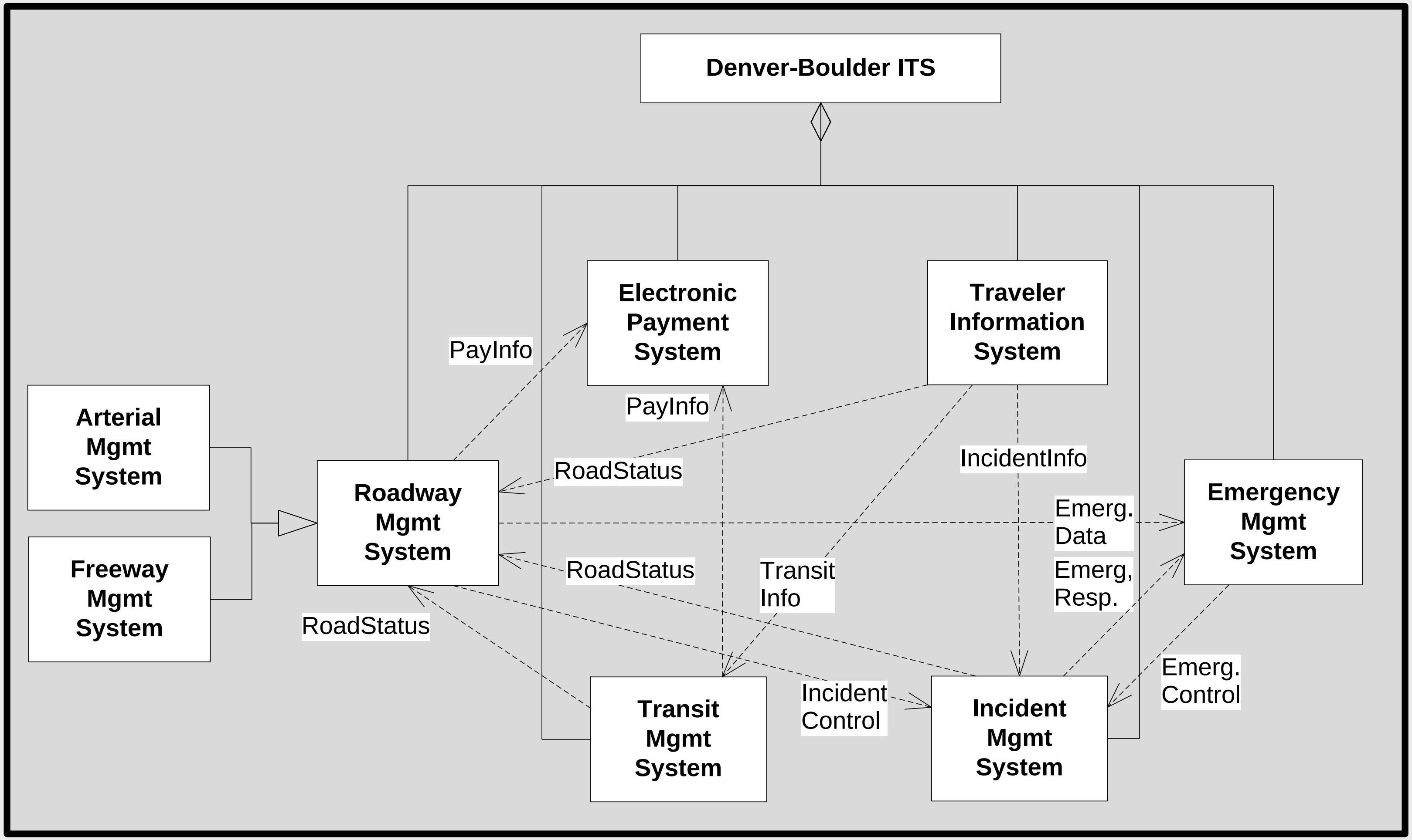


Define System Boundaries in terms of:

- Entities
- Relationships
- Permeability
- Interdependence
- Hierarchy
- Relationship to External Factors (Environment, Operator, etc.)

Denver-Boulder ITS High-Level Class Diagram with Interfaces



Denver-Boulder ITS Detailed Class Diagram

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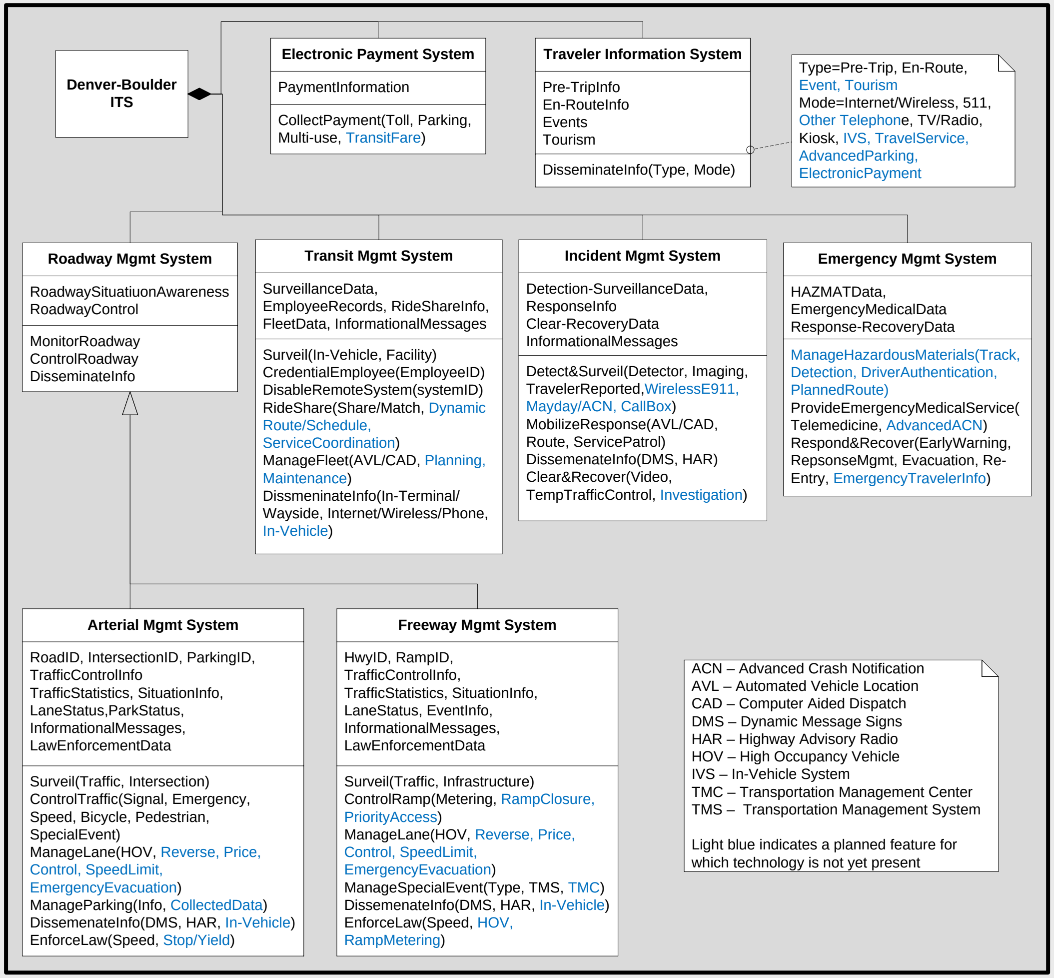

Denver-Boulder ITS MOEs and MOPs (1 of 2)

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Component	Area	System MOE Examples	Component MOP Examples
Roadway Management	Survey & Detect	Percentage of roads, percentage of intersections & ramps with electronic data collection, video, audio.	Audio detection frequency (Hz), sensitivity (dB). Video band, frame size (pixels), data rate
	Control	Percentage of signalized intersections with: signal priority for transit/emergency vehicles, signal controls, variable speed limit, ped/bike signals Percentage of freeway ramps with: ramp metering, ramp closure, priority access for transit vehicles	Control data rate & bandwidth, control delay, Control message latency, accuracy.
	Lane	Percentage of roads with: HOV, reversible lanes, lane control (e.g. closure), variable speed limit, support emergency evacuation	Time to reverse/close lane,
	Parking	Parking availability monitored and distributed?	Availability timeliness, accuracy.
	Special Event	Portable transportation management systems deployed?	Transmission range to ITS node, date rate, latency
	Info	Number of DMS deployed, percentage of road miles covered by HAR. Are IVS used?	DMS range to data link node. Data rate, accuracy. IT requirements, compute power, data storage, etc.
	Enforcement	Automated speed enforcement employed? Percentage of signalized intersections using photo enforcement	Speed, identification accuracy. Photo enforcement detection accuracy.
Incident Management	Survey & Detect	Number of magnetic/acoustic sensors per centerline mile. Percentage of road miles with video. Wireless 911/ACN systems deployed? Call boxes per road mile. Is traveler reported information collected and used?	Audio detection frequency (Hz), sensitivity (dB). Video band, frame size (pixels), data rate
	Mobilize & Respond	EMS use AVL/CAD to locate reported incidents? Is there a response routing system? Patrols per road mile.	AVL location accuracy, timeliness. CAD dispatch delay, accuracy.
	Clear & Recover	Automated systems used to clear incident? Video to support data collection? Temporary traffic control devices used?	Clearance time required. Video band, frame size (pixels), data rate
	Info	Number of DMS systems deployed, number and percentage of centerline miles covered by HAR.	DMS transmit range to ITS node, date rate, latency. HAR frequency, timeliness, accuracy of broadcast. IT requirements, compute power, data storage, etc.

Denver-Boulder ITS MOEs and MOPs (2 of 2)

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Component	Area	System MOE Examples	Component MOP Examples
Transit Management	**Safety & Security**	Percentage of transit/EMS vehicles with AVL/CAD, automated maintenance monitoring?	AVL location accuracy, timeliness. CAD dispatch delay, accuracy. Maintenance accuracy, timeliness.
	Transport Demand	Ride sharing/carpool matching, service coordination, dynamic routing/scheduling?	Database size, time to perform match, personal data security.
	Fleet	Percentage of transit/EMS vehicles, transit stations with audio/video surveillance systems.	Audio detection frequency (Hz), sensitivity (dB). Video band, frame size (pixels), data rate. Range.
	Info	Percentage of transit/ EMS vehicles using IVS . Percentage of transit stations using in-terminal displays. Internet, wireless, phone to distribute information?	IT requirements, compute power, data storage, etc.
Emergency Management	**HAZMAT**	Does the system track HAZMAT and authenticate drivers, use HAZMAT detectors, provide route planning?	HAZMAT track quality (pos, vel), accuracy, timeliness, latency.
	EMS	Does the system use ACN data, are ambulances telemedicine capable?	Crash notification timeliness, accuracy.
	Response & Recovery	Early warning capability, AVL/CAD to locate incidents, coordination of evacuation and traffic management, emergency traveler information?	Probability of early warning, accuracy, timeliness. AVL location accuracy, timeliness. CAD dispatch delay, accuracy.
Electronic Payment	**Toll**	Percentage of toll stations with electronic collection systems (e.g., smartcard).	Toll accuracy, reader accuracy
	Transit Fare	Percentage of transit vehicles with electronic collection systems (e.g., smartcard).	Fare accuracy, reader accuracy
	Parking	Are automated parking fee payment systems deployed?	Fee accuracy, reader accuracy. System resilience (to theft, for example).
	Multi-use	Electronic collection systems compatible across system?	Multi-use accuracy, reader accuracy
Traveler Info	**Pre-Trip & En-Route**	Use internet/wireless, 511, other telephone, radio/TV, kiosks to distribute pre-trip/en-route info?	Timeliness, accuracy, completeness of data.
	Tourism & Events	Provide traveler service information (lodging, points of interest, etc.), parking information?	Timeliness, accuracy, completeness of tourist, parking data.

References

[1] Maier, M. W. and Rechtin, E., *The Art of Systems Architecting, Third Edition*. Boca Raton, FL: CRC Press, 2009, pp. 115-123.

[2] Maier, M. W., On Architecting and Intelligent Transport Systems, IEEE Transactions on Aerospace and Electronics Systems, Vol. 33, No. 2, 2 April 1997, pp. 610-625.

[3] http://en.wikipedia.org/wiki/Intelligent_transportation_system

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Working Group 3:

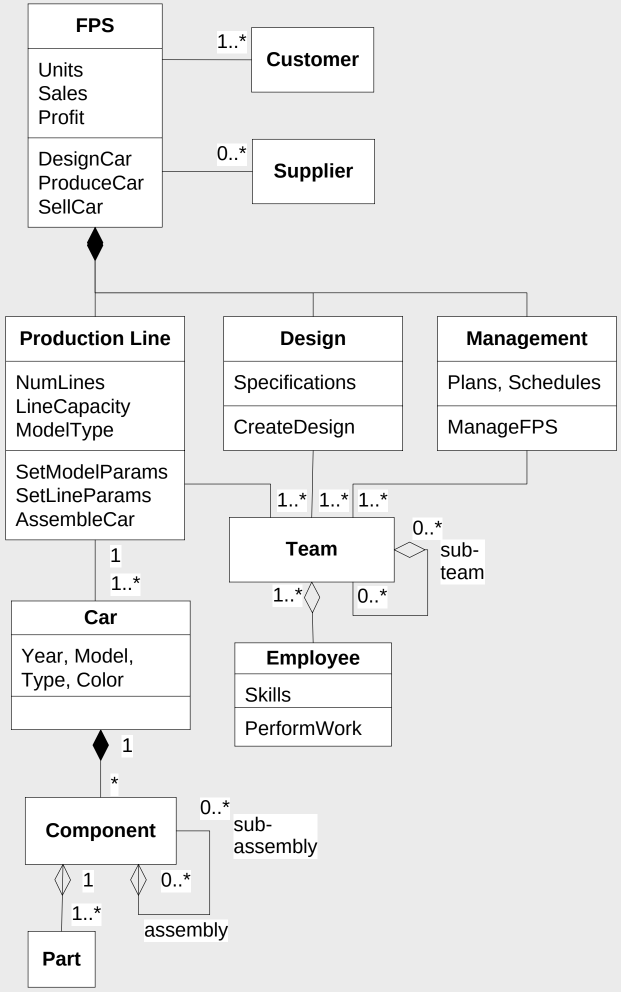
Operations Analysis for Systems of System within a Networked C2 Context

FORD PRODUCTION SYSTEM

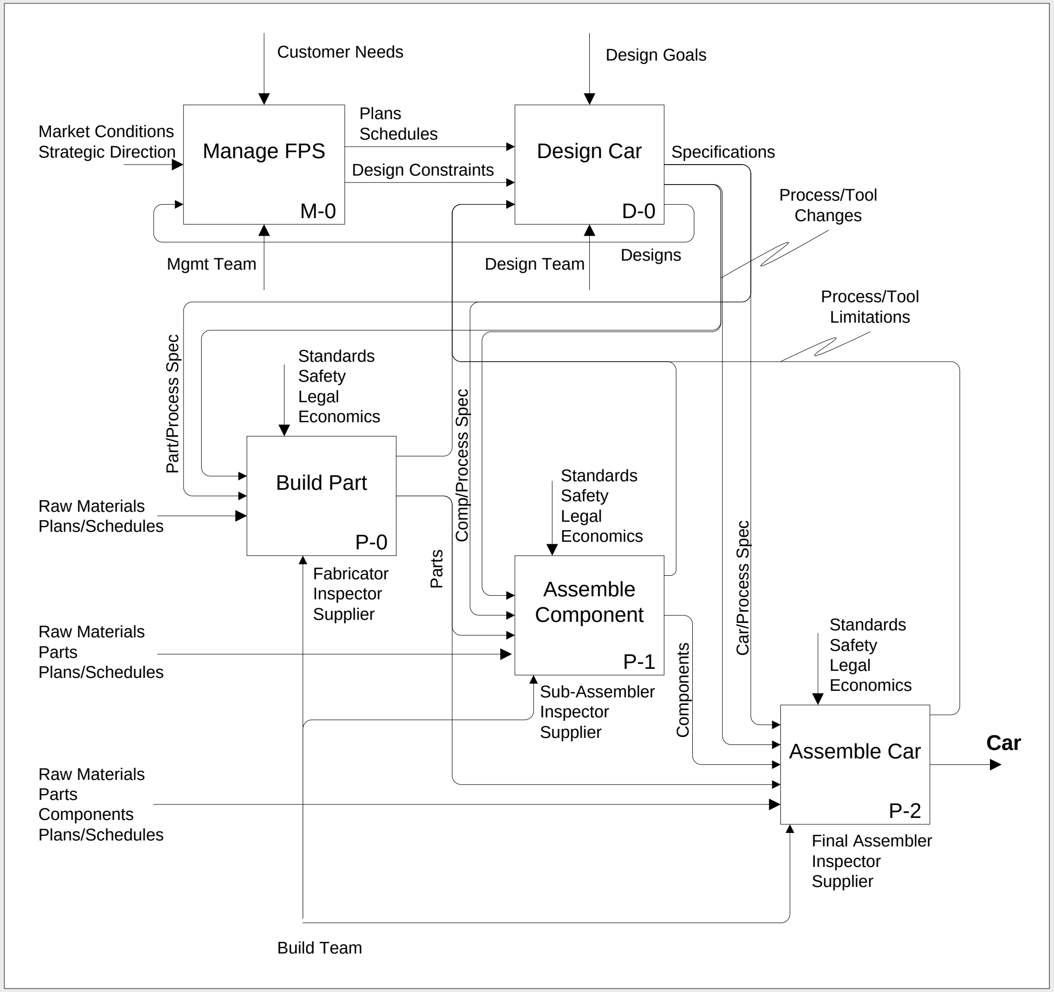
Ford Production System (FPS)

- A case study of a civilian production system:
- System Diagrams
  - **The first figure shows a simple class diagram for the Ford Production system (FPS). The class diagram does not explicitly show dependencies between production line, design, and management; however, each class can affect the other classes. For example, design change may cause the production line to change, or a production line limitation may constrain new design possibilities. Consider this class diagram to be a stable intermediate state. The second figure shows the simplified functional flow for the FPS.**
- System Risk/Opportunity
  - **The table outlines areas where FPS and Toyota Production System (TPS) address architectural risk**

Ford Production System Class Diagram



Ford Production System Functional Diagram (IDEF0)



FPS Discussion: Production Line & Modularity

From the standpoint of the class diagram and functional flow both the FPS and TPS have a lot in common. This comes from the fact that the TPS is based on the mass production concept but overlaid with lean manufacturing concepts. The basic functions and activities are similar; however, how these operations are carried out is somewhat different as are the interactions between classes. It may require behavior diagrams to identify the differences. Ford focused on a machine view of the system where the human served the production line. The processes were established to eliminate thought and skill from the process as much as possible. Toyota takes a more holistic view of the place of the human within the production process and recognizes that the quality, productivity, process improvement, and morale are all increased when the needs of the worker are also accounted for. TPS adapted the FPS, which was highly skewed toward technical aspects of mass production, and included a greater focus on the social aspects of mass production. TPS was driven as much by the economies (through elimination of waste – muda, mura, muri) that could be achieved by that focus as the social good that the more holistic view provided.

Ford applied the concept of modularity in both an architectural and system fashion. The major architectural approach to modularity was to break down the production of the car into discrete, sequential steps and to implement the moving assembly line by which the car moved past various workstations in turn for assembly from start to finish. From a system standpoint the production line was designed so that multiple shifts could operate independent from each other and produce the same car through the same processes in the same amount of time.

FPS Discussion: Options Analysis & Risk

Ford option analysis focused on wringing every possibly economy out of the mass production model, making the assembly line as efficient and cost effective as possible. Ford's main approach seemed to be to optimize architecture for least cost at any particular point while Toyota addressed elimination of sources of waste, thereby reducing cost, across the entire enterprise. TPS may be more flexible to sub-optimize any part of the process so that the entire process is optimized. Toyota focused on economizing the entire enterprise from supplier to producer to consumer.

An example where options analysis applied to modularity may have improved the system has to do with Ford's concept to simplify individual tasks as much as possible so that a worker stayed in one place doing one task at a particular station on the assembly line. One downside of the Ford approach was social alienation of the worker, boredom, and repetitive stress injuries. This increased the risk of defects through inattention and only being able to recognize defects in a very limited scope. A real options approach could have balanced cost, worker satisfaction, work modularity, and quality/safety. The completion of a component of the car may require the use of multiple tools to assemble all parts and sub-assemblies. In the FPS system one operator mans each tool and the component is passed from operator to operator until it is assembled. In the TPS system a single operator may be responsible to carry the component from station to station and perform the assembly task at each station. The FPS systems requires a number of operators based on the number of tooling stations so an individual operator may be idle at times depending on the rate of production. In the TPS system the number of operators can be varied to reduce idle time based on the production rate. In the TPS system the operator must be more skilled because he must learn multiple tasks. This has an advantage in that it should generally improve worker satisfaction through variety and increase quality, thereby reducing enterprise cost, through ownership and better understanding of entire component. The downside as compared to FPS is that more skilled labor is required, and FPS seeks to eliminate the need for skill and therefore reduce cost.

Risk/Opportunity Sources Addressed by Architecture (1 of 2)

Risk/Opportunity Source	Addressed by Architecture? (Yes, No, Partial)			
	FPS	Comment	TPS	Comment
Overproduction	Part	Ford production "pushes" through the line so requiring more capital/storage and higher risk of overproduction if market is misjudged.	Yes	Greater focus on just in time techniques. Less storage/capital outlay required (Muda)
Inventory Control	Part		Yes	
Unnecessary Transportation	Yes	Combined material processing, manufacturing, and assembly at plant	Yes	Reduce risk of damage, loss, or delays to product(Muda)
Motion (worker/equipment)	Yes	Introduced standardized parts and processes.	Yes	Reduce damage and wear, increase safety (Muda)
Defects	Part	Product standardized reduces defects, but may be offset by unskilled labor	Yes	Reduced defects = reduced cost of rework/delays (Muda)
Overprocessing	Part	Transformed craft production to mass production	Yes	Use tools only as precise, complex, or expensive as to meet customer need to reduce cost (Muda)
Waiting	Part	Moving assembly line	Yes	Reduced waiting = reduced risk of damage, loss and less storage required (Muda)
Latent Skill	No	Workers had one job at one position; reduced flexibility/ adaptability, affects defect rate and morale through boredom	Part	Capitalize on employees others skills to improve their performance and processes. Developing people adds value. (Muda)

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Risk / Opportunity Sources Addressed by Architecture (2 of 2)

UNCLASSIFIED

Risk/Opportunity Source	Addressed by Architecture? (Yes, No, Partial)			
	FPS	Comment	TPS	Comment
Production Leveling	Part	Improved processes enabled shorter work hours and expanded work from 2 to 3 shifts. Most effective when assembly line operating at full capacity (push).	Part	Frequent deliveries to customer helps eliminate overproduction (pull). Merge sub-processes under single worker. Suboptimal for processes requiring long lead times (Mura)
Work Flow Optimization	Yes	Standardized processes, interchangeability	Yes	Improved quality/productivity, reduced cost, better morale (Muri)
Repeatable Processes, Machine Processes	Yes	Decompose complex tasks w/ special purpose tools. Improved quality/productivity, reduced cost, adaptable flexibility (Fordism)	Yes	
Reasonable Process Time	Yes	Optimized processes to reduce production time	Yes	
Producing goods that do not meet customer demands or specifications	Part	Model T focused on cost reduction through mass productions ("push" model). Later displaced by complex mixture of engineering, production, and marketing which Ford had to catch up to.	Yes	TPS organized manufacturing & logistics, but included interactions with suppliers and customers. Everyone in process is considered as a customer and supplier ("pull" model).
Product Standardization	Yes	Standard parts and processes; improved quality and reduced assembly time (Fordism)	Yes	Standard parts and processes; improved quality and reduced assembly time (copied from Fordism)
Elimination of skilled labor	Yes	Direct production using unskilled labor is less expensive but can increase defect rate, for example	No	Developing people adds value. (Muda)

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Operations Analysis for Systems of System within a Networked C2 Context

HEALTHCARE NETWORK EXAMPLE

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- SOS/Complex System definition
- C2 definition (I would assume it could include C2, C3, CIS, C3I, C4I,C4ISR, C2BM, C2BMC, etc)
- Formulating MOEs/MOPs (esp. in context of C2)
- As OSI-like framework for C2 networks (to help define the types of MOEs pertaining to different views of the system)
- Network as a Cloud
- Mission definition, Commander's Intent and System/Problem context
- Quantitative & Qualitative assessment of the system