30th Annual INCOSE international symposium

Virtual Event
July 20 - 22, 2020

July 22, 2020: 17:50-18:30 South Africa Standard Time (Track 2, Session 9.2.3)

Case Study: Achieving System Integration through Interoperability in a large System of Systems (SoS)

Oliver Hoehne, PMP, CSEP, CSM
Technical Fellow, Systems Engineering
WSP USA
oliver.hoehne@wsp.com

www.incose.org/symp2020

Presenter Bio

Oliver Hoehne

- Born and Raised in Berlin, Germany, Living in USA for ~20 Years
- Apprenticeship / Customer Service Technician
- B.Sc. (Dipl.-Ing.[FH]) in Computer Science
- International Experience Working in Europe and North America
- Background in Large Transportation & Infrastructure Projects
- Systems Engineer, Design Manager, Deputy Chief Systems Engineer, Systems Integrator and Project Manager Roles
- Project Management Professional (PMP)
- Certified Systems Engineering Professional (CSEP)
- Technical Fellow, Systems Engineering
- Active Member of INCOSE SoS Working Group

AGENDA

- **Introduction**
  - System of Systems (SoS)
  - California High-Speed Rail System (CHSRS) Program
  - CHSRS as a System of Systems
- **SoSE Challenges Faced**
  - Traditional Industry Approach to Systems Integration
  - SoS Engineering Challenges
- **SoSE Activities Performed**
  - International Best Practice Analysis of HSR System Integration
  - SoS Integration Strategy
  - Step by Step Process Description
- **Summary, Achieved Outcomes & Conclusion**

Introduction: System of Systems

SoS Definition & Characteristics

ISO/IEC/IEEE 15288:2015(E)

Annex G
(informative)

Application of system life cycle processes to a system of systems

G.1 Introduction

A system of systems (SoS) is a system-of-interest (SOI) whose elements are themselves systems. A SoS brings together a set of systems for a task that none of the systems can accomplish on its own. Each constituent system keeps its own management, goals, and resources while coordinating within the SoS and adapting to meet SoS goals. In the context of terminology discussed in subclause 5.2.3 (as shown in Figure 3), the composite set of systems including the original SOI, enabling systems and interacting systems, together constitute an SoS. Where there are concerns that affect the composite set, the system of systems becomes the SOI, which is considered to satisfy some business or mission objective that cannot be satisfied by the individual constituent systems, or to understand emergent behavior of the combination.

This annex addresses the application of system life cycle processes to such SoS. It describes general characteristics, the common types of SoS, and the implications throughout the life cycle.

G.2 SoS characteristics and types

SoS are characterized by managerial and operational independence of the constituent systems, which in many cases were developed and continue to support originally identified users concurrently with users of the SoS. In other contexts, each constituent system itself is a SOI; its existence often predates the SoS, while its characteristics were originally engineered to meet the needs of their initial users. As constituents of the SoS, their consideration is expanded to encompass the larger needs of the SoS. This implies added complexity particularly when the systems continue to evolve independently of the SoS. The constituent systems also typically retain their original stakeholders and governance mechanisms, which limits alternatives to address the needs of the SoS.

SoS have been characterized into four types based on the governance relationships between the constituent systems and the SoS (Figure G.1). The strongest governance relations apply to directed system of systems, where the SoS organization has authority over the constituent systems despite the fact that the constituent systems may not have originally been engineered to support the SoS. Somewhat less control is afforded for acknowledged SoS, where allocated authority between the constituent systems and the systems of systems has an impact on application of some of the systems engineering processes. In collaborative SoS, which lack system of systems authorities, application of systems engineering depends on cooperation among the constituent systems. Virtual systems of systems are largely self organizing and offer much more limited opportunity for systems engineering of the SoS.

Emergence is a key characteristic of SoS – the unanticipated effects at the systems of systems level attributed to the complex interaction dynamics of the constituent systems. In SoS, constituent systems are intentionally considered in their combination, so as to obtain and analyze outcomes not possible to obtain with the systems alone. The complexity of the constituent systems and the fact they may have been designed without regard to their role in the SoS, can result in new, unexpected behaviors. Identifying and addressing unanticipated emergent results is a particular challenge in engineering SoS.

ISO/IEC/IEEE 15288, 2015, Annex G

A **system of systems (SoS)** is a system-of-interest (SOI) whose elements are themselves systems.

A SoS brings together a set of systems for a task that none of the systems can accomplish on its own.

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SoS Characteristics: SoS are characterized by **managerial and operational independence of the constituent systems**, which in many cases were developed and continue to support originally identified users of the constituent concurrently with users of the overall SoS.

Introduction: System of Systems
SoS Types

ISO/IEC/IEEE 15288, 2015, Annex G

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SoS Types	Governance Relationships between SoS & CS
Directed SoS	❖ SoS created to fulfill specific purpose ❖ Dedicated SoS manager ❖ Subordinated constituent systems
Acknowledged SoS	❖ Recognized SoS objectives ❖ Designated SoS manager & resources ❖ Independent constituent systems
Collaborative SoS	❖ Agreed upon central purpose ❖ Voluntary interaction ❖ Independent constituent systems
Virtual SoS	❖ Lacks central management ❖ Lacks agreed upon purpose ❖ Large scale emergent behavior

INTRODUCTION: SYSTEM OF SYSTEMS

SOS EMERGENCE

ISO/IEC/IEEE 15288:2015(E)

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INTRODUCTION: SYSTEM OF SYSTEMS

INCOSE SoS PRIMER – FURTHER READING


INCOSE

INCOSE Systems of Systems Primer

INCOSE-TP-2018-003-0

Systems tend to…	Syste
Have a clear set of stakeholders	Have m and po
Have clear objectives and purpose	Have m objectiv
Have a clear management structure and clear accountabilities	Have d clear ac
Have clear operational priorities, with escalation to resolve priorities	Have m operati routes
Have a single lifecycle	Have m implem
Have clear ownership with the ability to move resources between elements	Have m resourc

Types of SoS

A taxonomy has evolved (proposed by Maier 1998, and extende been widely used to categorise SoS into four different types basi noting that SoS are often complex, and may be classed different are viewed at, or their current operating mode at any one time.

Directed SoS are built and managed to fulfill spe to ensure goals are met. Although constituent sy they accept that their normal operational mode is can be found in metropolitan transportation syste services may collaborate to deliver metro service direction in order to participate.

Acknowledged SoS have objectives recognized manager, and dedicated SoS resources. Constitu objectives, funding, development and sustainme are based on agreed collaboration. Air traffic con and safe airspaces globally all recognise their sh adhere to regulations and protocols.

Collaborative SoS comprise constituent system some central purposes, which can evolve based An electrical grid is an example. Autonomous co electricity to consumers. Unlike an acknowledge Constituent systems adhere to standards and re roles and working practices.

Virtual SoS have no central authority, nor an exp SoS can exhibit large-scale emergent behavior, The internet is an example. The Internet Engine standards and protocols. Independent service pr products. No management or governance is eith there is no central purpose for all parties.

INCOSE Systems of Systems Primer

SoS Authority

How do we handle collaboration and agreement when there is no overall director? Effective patterns for collaboration are needed, but are often difficult to recognise or establish. The defense sector tackles this with a focus on finding ways to balance the values & needs of constituent systems with those of the SoS. Other application domains tackle this through incentivizing constituent systems, creating an environment where they can meet their own goals whilst collaborating to support SoS goals.

SoS Principles

What are the key SoS thinking principles? Surveys of SoS practitioners have identified areas where basic principles are lacking. These include: lack of formalized SoS processes; lack of SoS success stories; and information about workflows. Much more research on SoS working contexts is needed to develop a body of recognized best practice.

Leadership

What are the roles & characteristics of effective SoS leaders? The increasingly complex collection of independent systems in an SoS typically straddles disciplines, application domains, organizations and even national boundaries, and each constituent system is capable of following their own interests and agenda. As a result, effective means of leadership are important. Structure and directorship usually found in SE projects is often absent for SoS, and other methods are needed to ensure coherence and direction.

Constituent Systems

How to integrate constituent systems? Each constituent system has its own agenda and goals, and can act autonomously. Some may be legacy systems not designed for SoS contexts, not easily adapted, resulting in interoperability challenges. Operating an SoS means finding means to coordinate, incentivize and manage multiple separate constituent systems, with separate working cultures, schedules, processes and working practices, as well as coping with technical challenges such as communications and data exchange. Mismatched assumptions and expectations are a real risk.

INCOSE Systems of Systems Primer INCOSE-TP-2018-003-01.0

SoS Pain Points

What does a systems engineer need to know about SoS?

Many existing systems do play a role in an SoS, whether they are explicitly aware of this or not. Working in an SoS context brings a number of challenges, and it can help to be aware of these. Surveys conducted by the INCOSE SoS Working Group have identified "pain points" which are particularly associated with SoS by practising systems engineers (summarized by Judith Dahmann 2014).

[1] COMPASS project: http://thecompassclub.org/
[2] DANSE project: http://danse-ip.eu/home/
[3] INTO-CPS project: http://projects.au.dk

Autonomy, Interdependence & Emergence

can system engineering address the complexities oS inter-dependencies and emergent behaviors? ndent, uncoordinated evolution of constituent systems o unanticipated emergent effects at the SoS level, often ervable until the SoS is simulated or tested. Complex endencies are common between constituent systems rent stages of maturity, often not well understood or nted. The scale, diversity & independence in an SoS es it difficult to produce models that can accurately ct SoS-level performance. Recent work has begun esearch SoS and emergence, SoS uncertainty & omplexity, and modelling & simulation – see, for example, [1, 2, 3].

INCOSE-TP-2018-003-01.0

California High-Speed Rail System (CHSRS)

Brief Introduction

WSP WHO WE ARE WHAT WE DO INSIGHTS CAREERS Investors News Contact us GLOBAL - ENGLISH FRANÇAIS

Source: https://www.wsp.com/en-GL/projects/california-high-speed-rail

CALIFORNIA HIGH SPEED RAIL

California High-Speed Rail System (CHSRS)

Key Highlights

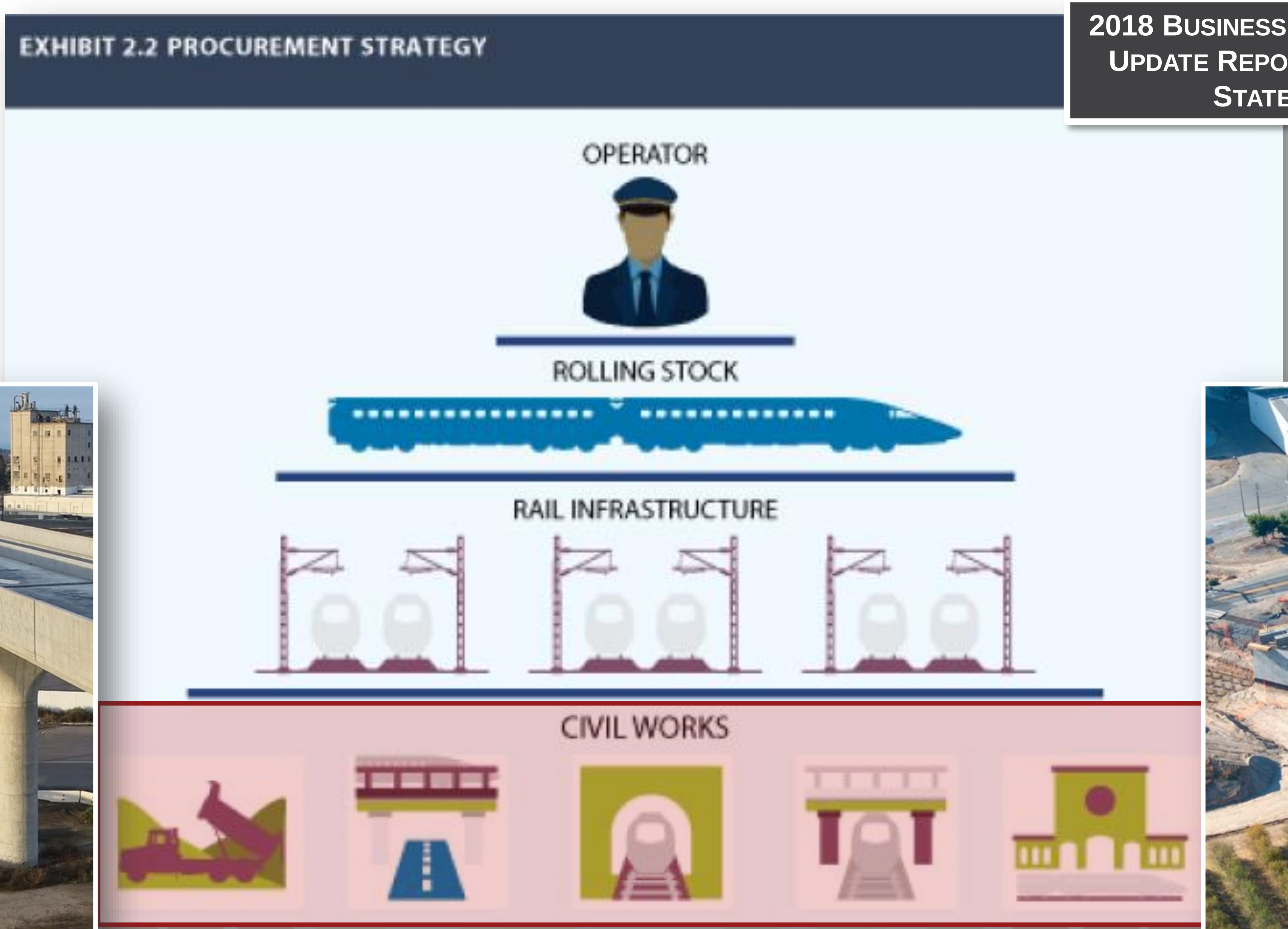
- One of the largest and most ambitious public transportation programs in U.S. history
- Will allow passengers to travel from Los Angeles to San Francisco at speeds of up to 220 miles (354 kilometers) per hour
- Trip in just 2 hours and 40 minutes, compared to almost 6 hours by automobile
- Connects California's megaregions, contributes to economic development and a cleaner environment, creates jobs and preserves agricultural and protected lands
- Using federal and state funds, including Cap and Trade, Authority plans to begin high-speed operations to begin in the Central Valley by 2028
- Will eventually connect San Francisco to Los Angeles in under three hours at speeds of 350km/h (220mph) by 2033, extending to Sacramento and San Diego, totaling 800 miles with up to 24 stations
- Improves local and regional rail lines

2019 Project Update Report to the California State Legislature

California High-Speed Rail System (CHSRS)

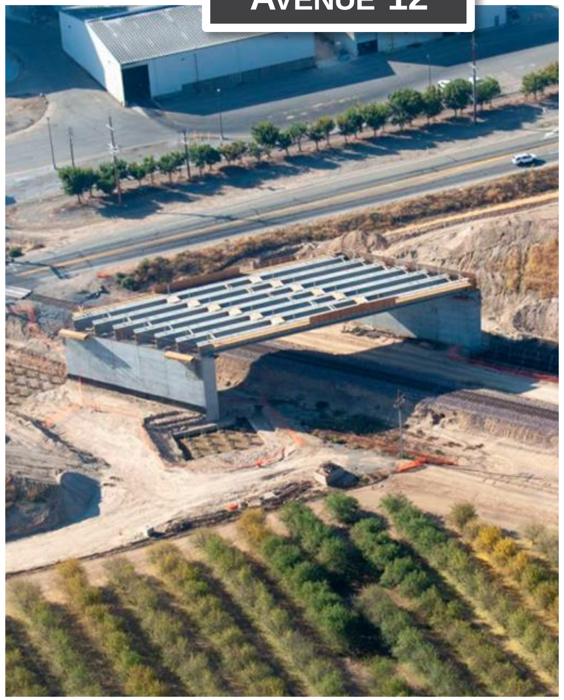
Procurement Strategy

2018 Business Plan & 2019 Project Update Report to the California State Legislature



Cedar Viaduct

Avenue 12



CHSRS as a System of Systems

CHSRS as a Constituent System within a Larger SoS

Interfacing Systems & Organization

Interfacing Systems & Organization

Adjacent Railroads

Power Utilities

Seismic Detection

River Crossing

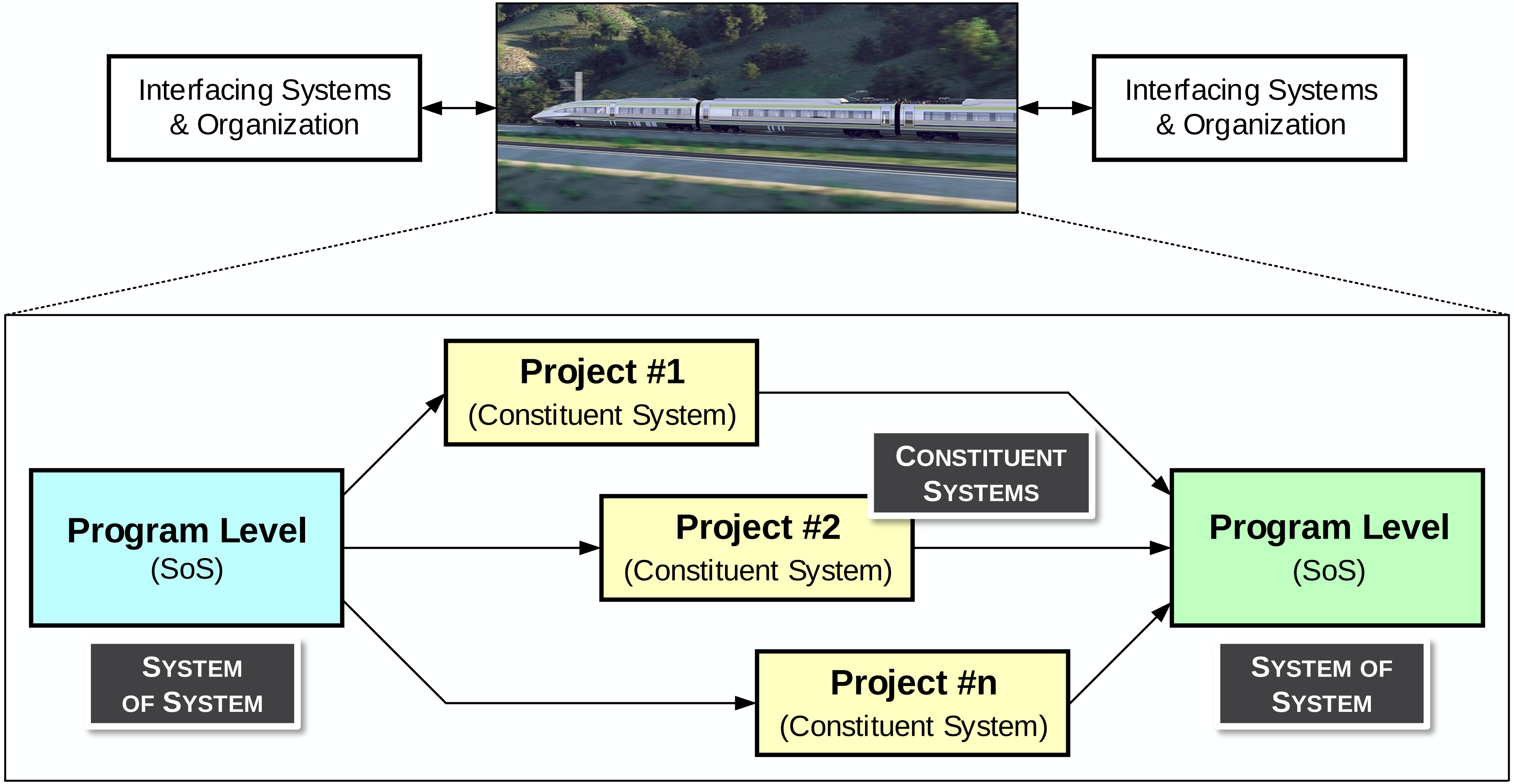
Adjacent Roadways

Shared Corridors

Source:
https://www.youtube.com/watch?v=AKsjqu3l0xA

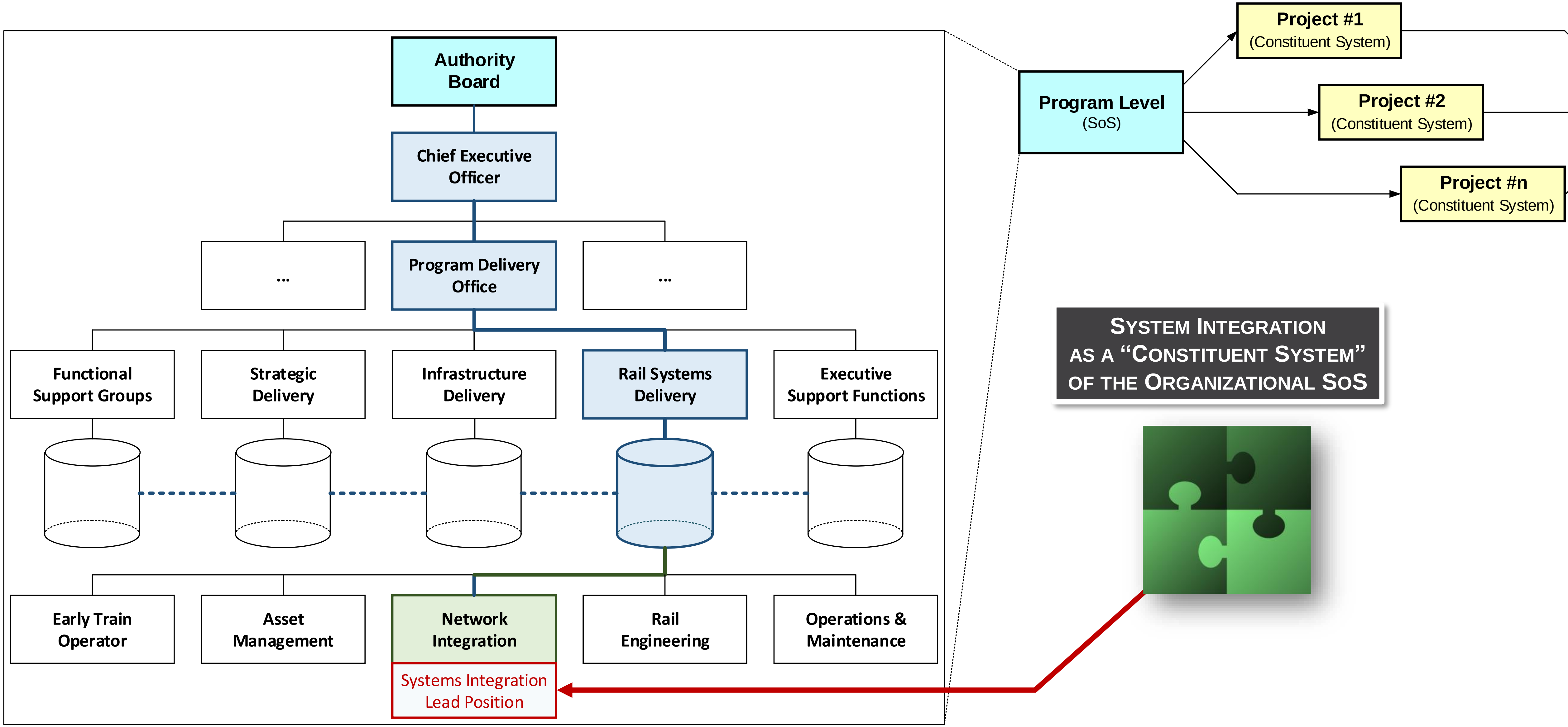
CHSRS as a System of Systems

CHSRS as a Program (SoS) of Projects (Constituent Systems)



CHSRS AS A SYSTEM OF SYSTEMS

CHSR PROGRAM ORGANIZATION AS AN ORGANIZATIONAL SOS



PROGRESS

- **Introduction**
  - System of Systems (SoS)
  - California High-Speed Rail System (CHSRS) Program
  - CHSRS as a System of Systems
- **SoSE Challenges Faced**
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  - Step by Step Process Description
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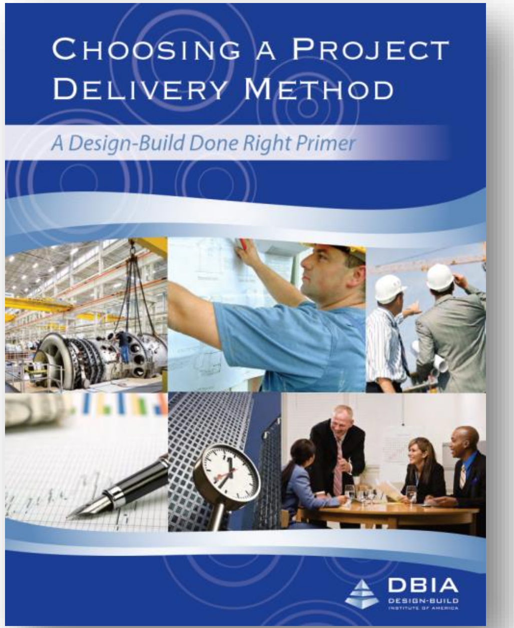
Traditional Industry Approach to Systems Integration

Project Delivery Methods

Traditional Method
(Design / Bid / Build)



Project Initiation ◇ → Planning | Preliminary Engineering | Final Design → Bid ◇ → Construction | Operations & Maintenance → ◇ Project Closeout

Owner Organization
(Functional Structure)

Integration Challenges & Change Orders

Construction Firm

Today's Preferred Method
(Design / Build)

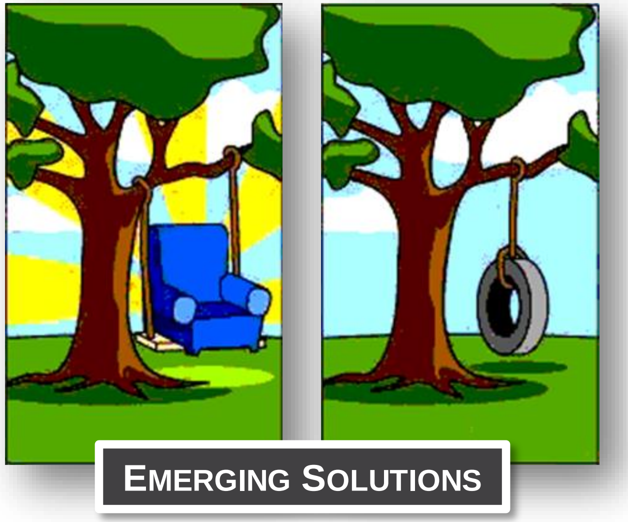
Project Initiation ◇ → Planning | Preliminary Engineering → Bid ◇ → Final Design | Construction | Operations & Maintenance → ◇ Project Closeout

(Integration) Risk Transfer to Design & Construction Firm

Traditional Industry Approach to Systems Integration

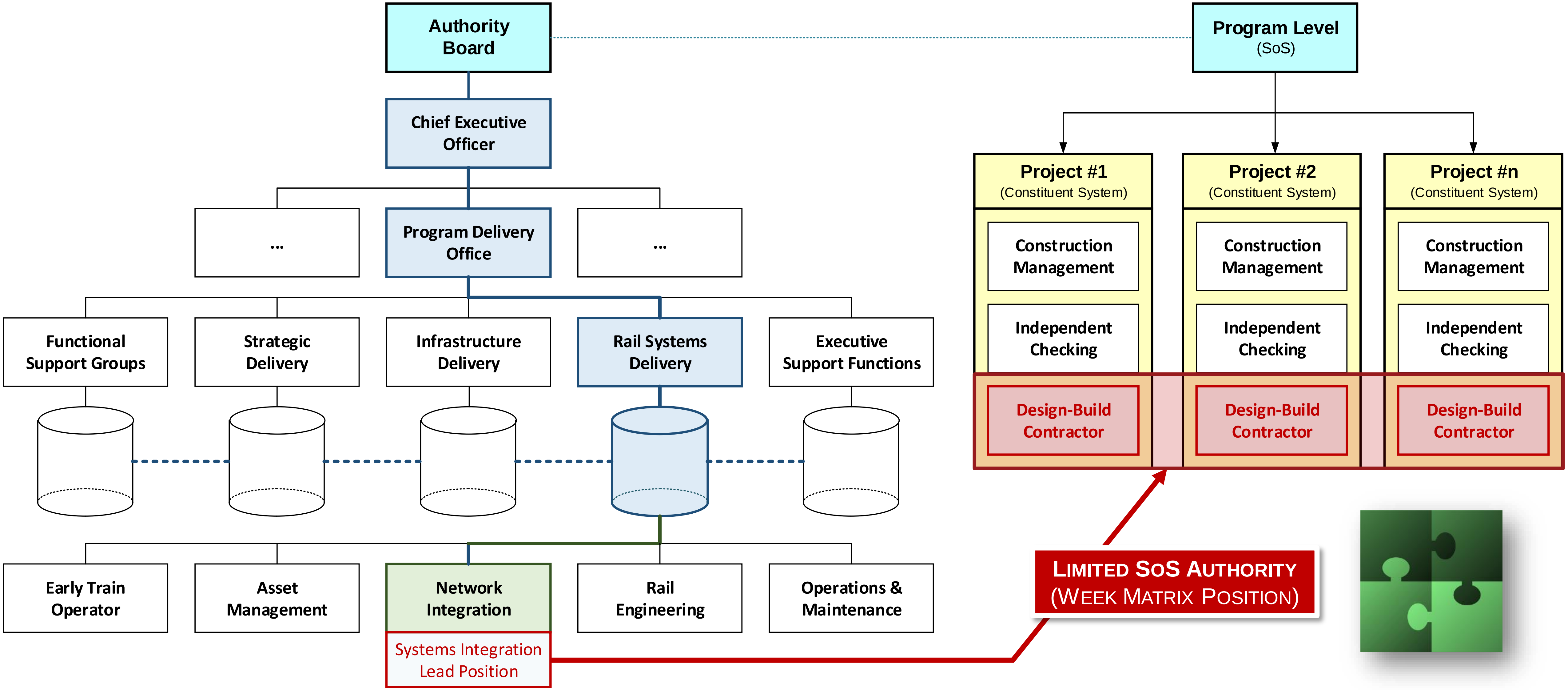
Consequences of Design / Build (DB)

- **Reluctance to be Specific:**
  - Interference with design / construction firm's business, possibility of "re-owning" the risk
  - Detailed directions may result in additional work order claims
- **Unknown System Integration Scope:**
  - Design / construction firm responsible for final design & construction
  - Limited knowledge of final solution at time of bid (i.e. system architecture & interfaces)
  - Resulting in hesitance to provide detailed interfaces lists & descriptions (see above)
  - Risk of omitted interfaces may be subject to additional work order claims
- **Innovative Design & Construction:**
  - Saving time and money by encouraging collaboration and innovation
  - May result in (emerging) unanticipated and/or unintended design solutions
- **Design / Build Impact to Systems Integration:**
  - Systems integration becomes "coordination" responsibility (scope)
  - Risk avoidance approach (hands-off, "leave it to the contractor")
  - Often reactive, late interface identification during final design & construction



SoSE Challenges Faced

SoS Authority



SoSE Challenges Faced

SoS Architecture & Leadership – Contract Packaging

Design-Build Construction Packages

The high-speed rail system is being built through a series of design-build contracts. Work within a design- **Civil Works** egi until a project section has been environmentally cleared. Currently, the Authority has identified four desi Central Valley. Construction updates and road closure alerts are posted on BuildHSR.com.

- Construction Package 1 (HSR 13-06) **Started in 2013**
  Construction Package 1 (CP 1) is the first significant construction contract executed on the Initial Operating Section of the high-speed rail program. The CP1 construction area is a 32-mile stretch between Avenue 19 in Madera County to East American Avenue in Fresno County. It includes 12 grade separations, 2 viaducts, 1 tunnel and a major river crossing over the San Joaquin River.

- Construction Package 2-3 (HSR 13-57)
  Construction Package 2-3 (CP 2-3) is the second significant construction contract executed on the Initial Operating Section of the high-speed rail program. The CP 2-3 construction area extends approximately 60 miles from the terminus of Construction Package 1 at East American Avenue in Fresno to one mile north of the Tulare-Kern County line. CP 2-3 will include approximately 36 grade separations in the counties of Fresno, Tulare and Kings, including viaducts, underpasses and overpasses.

- Construction Package 4 (HSR 14-32)
  Construction Package 4 (CP 4) is the third significant construction contract executed on the Initial Operating Section of the high-speed rail program. The CP 4 construction area is a 22-mile stretch bounded by a point approximately one mile north of the Tulare/Kern County Line at the terminus of Construction Package 2-3 and Poplar Avenue to the south. CP 4 will include construction of at-grade, retained fill and aerial sections of the high-speed rail alignment and the relocation of four miles of existing Burlington Northern Santa Fe (BNSF) tracks.

Contracts Out for Bid

Design-Build Construction Packages

Track & Systems

RESOURCES

- Cal eProcure

Source: https://hsr.ca.gov/business/contractors/contracts_out.aspx

SoSE Challenges Faced

SoS Architecture & Leadership (Cont'd)

Track & Systems

The Track and Systems procurement is proposed to be a design-build-maintain contract with a scope of work that includes design and construction of trackwork, railway systems, and electrification, as well as testing and commissioning. The Track and Systems contract, as proposed, will also include a 30-year term of maintenance for both the underlying civil works a Th Track and Systems work would be issued through multiple Notices to Proceed (NTP) for the Centr nt

Track & Systems

The anticipated schedule for this procurement is as follows:

- RFQ Release: July 17, 2019
- SOQ Due Date: November 4, 2019
- RFP Release: December 19, 2019
- Proposal Due Date: September 15, 2020

To be Started

RFP for Track and Systems

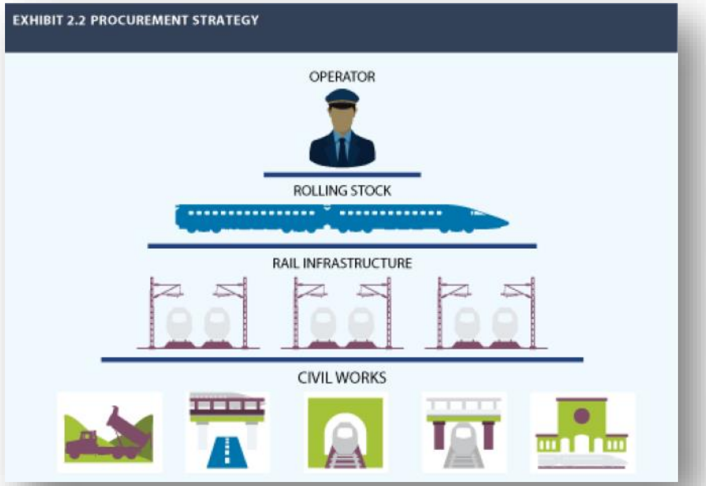
The Authority released the Request for Proposals (RFP HSR19-13) to three shortlisted teams on December 19, 2019. California High-Speed Rail Constructors notified the Authority on February 27, 2020 that their team has withdrawn from the Track and Systems RFP procurement process.
Please find below the small-business and non-small business contact information:

- Contracts Out for Bid
- Design-Build Construction Packages
- **Track & Systems**

Source: https://hsr.ca.gov/business/contractors/contracts_out.aspx

SoSE Challenges Faced

SoS Architecture & Leadership (Cont'd)



Train Operator

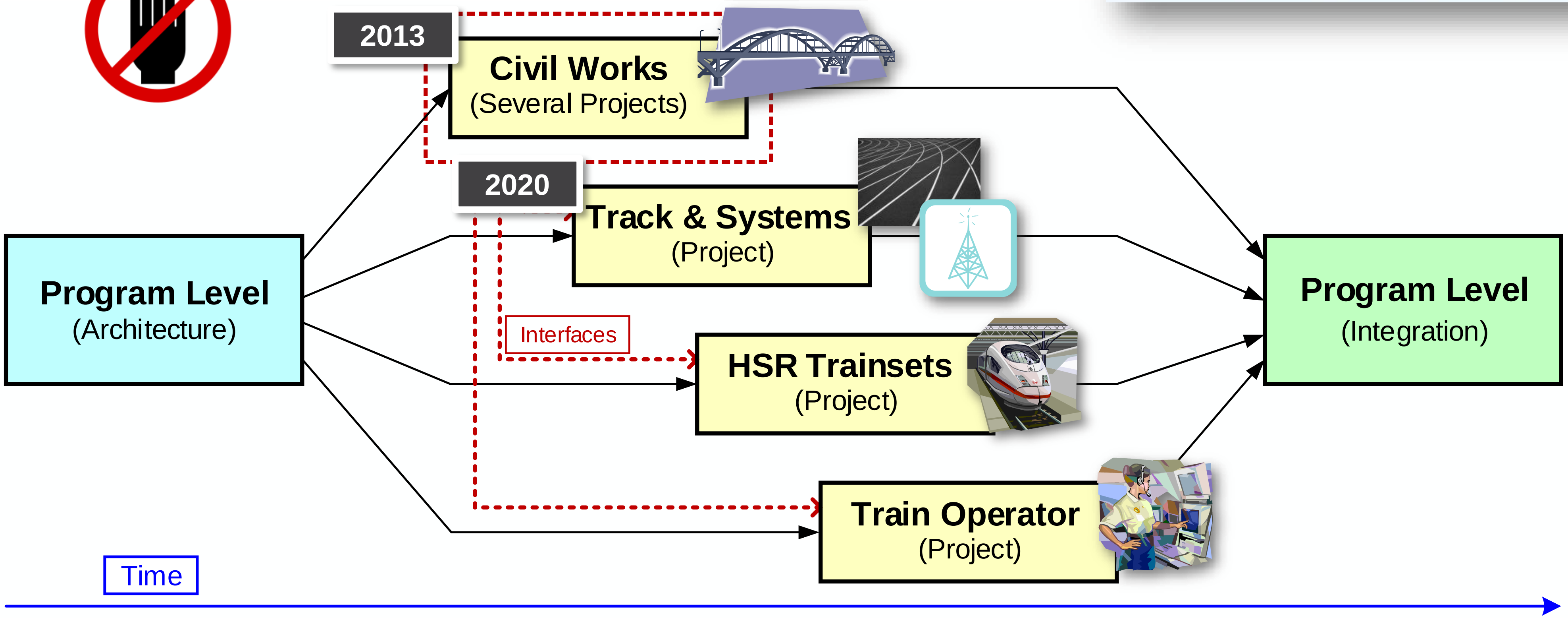
HSR Trainsets

Track & Systems

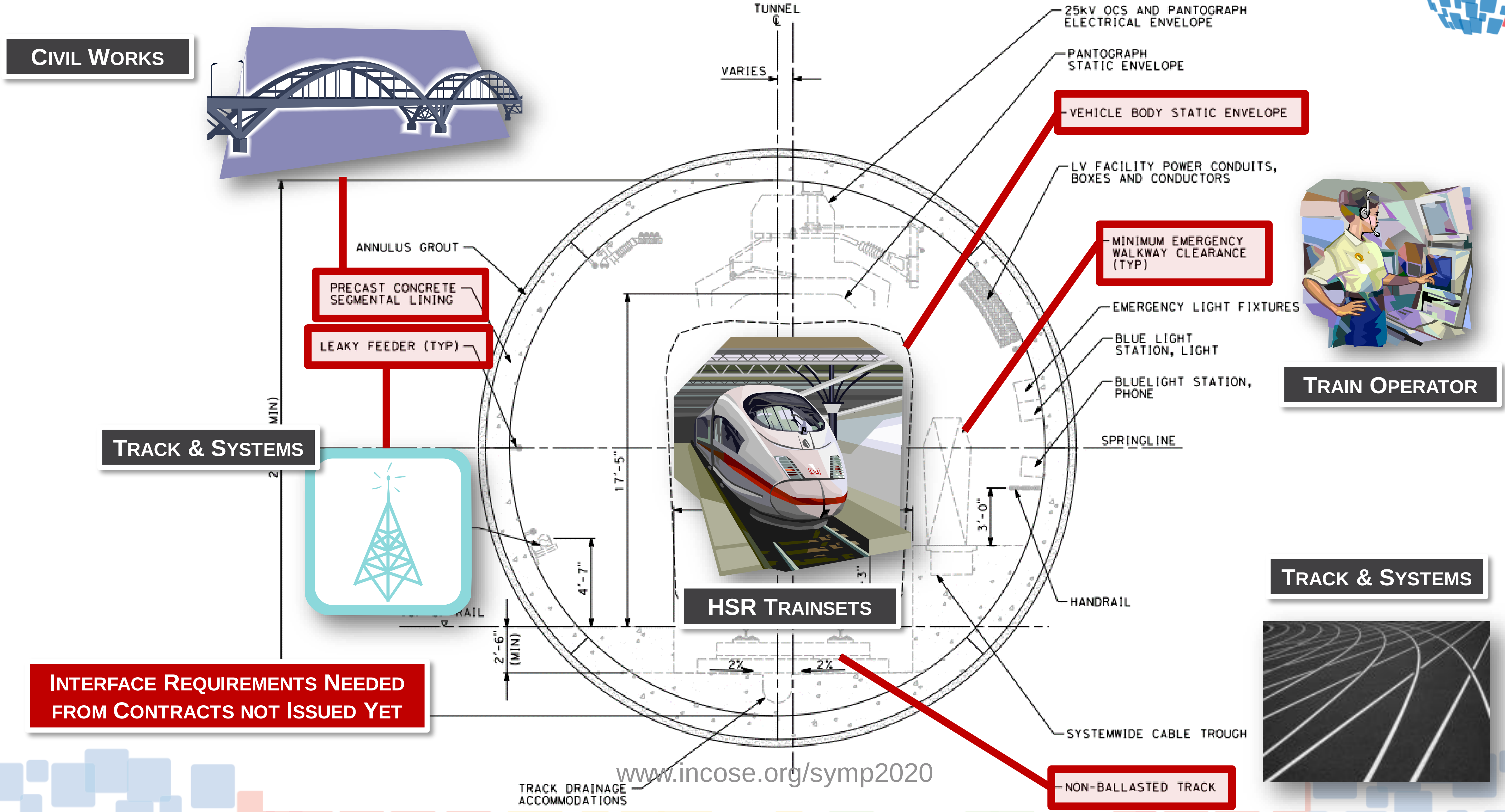
Civil Works

SoS Leadership
("Leave it to the Contractor")

SoS Architecture
(Contracts & Interfaces)

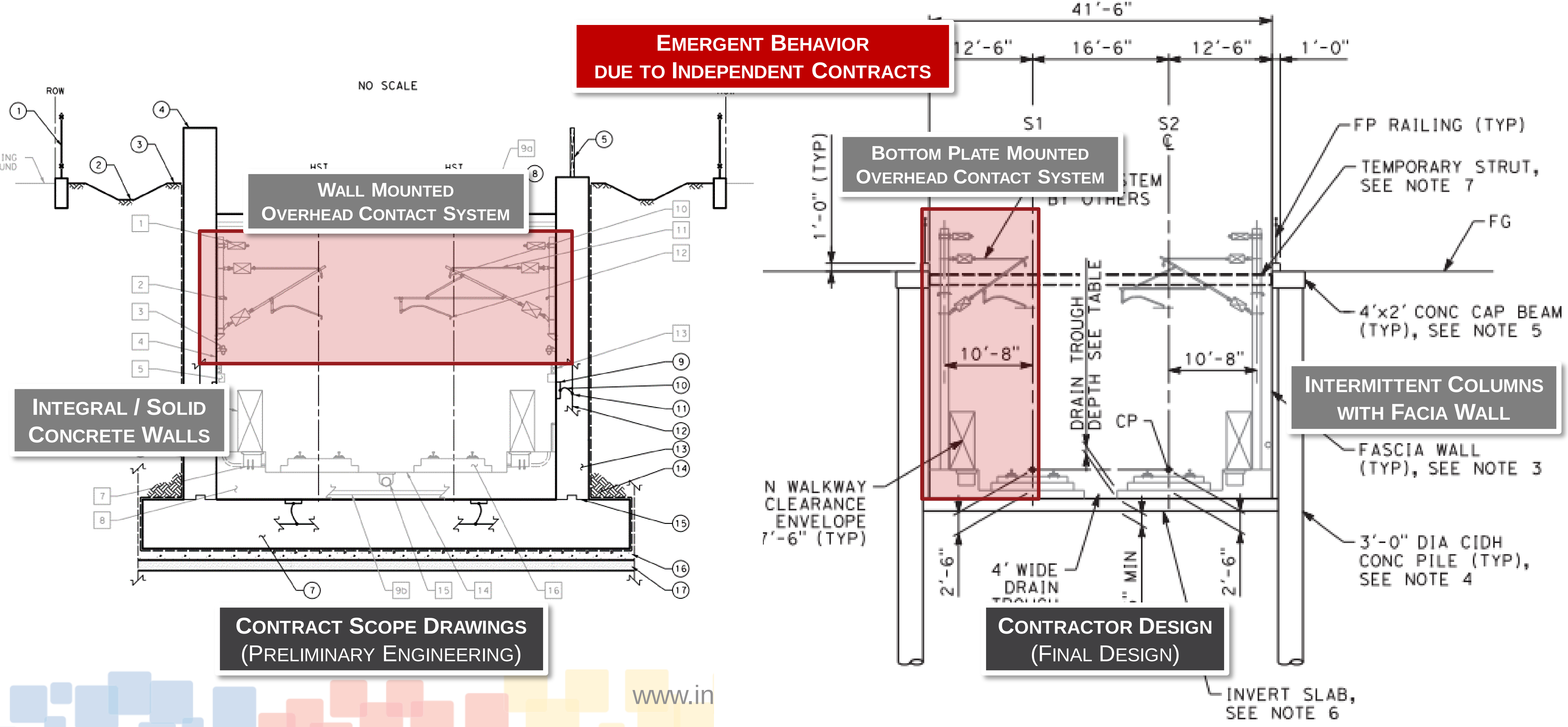


SoS Collaboration & Integration



SoSE Challenges Faced

SoS Autonomous Constituent Systems & Emergence



Progress

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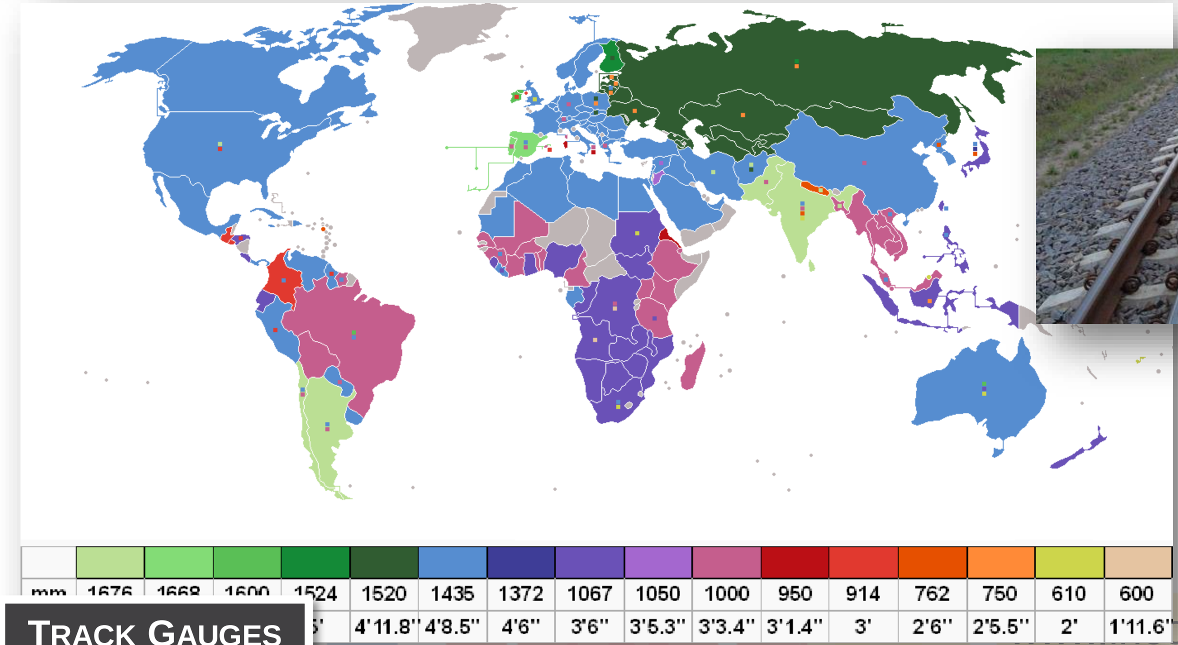
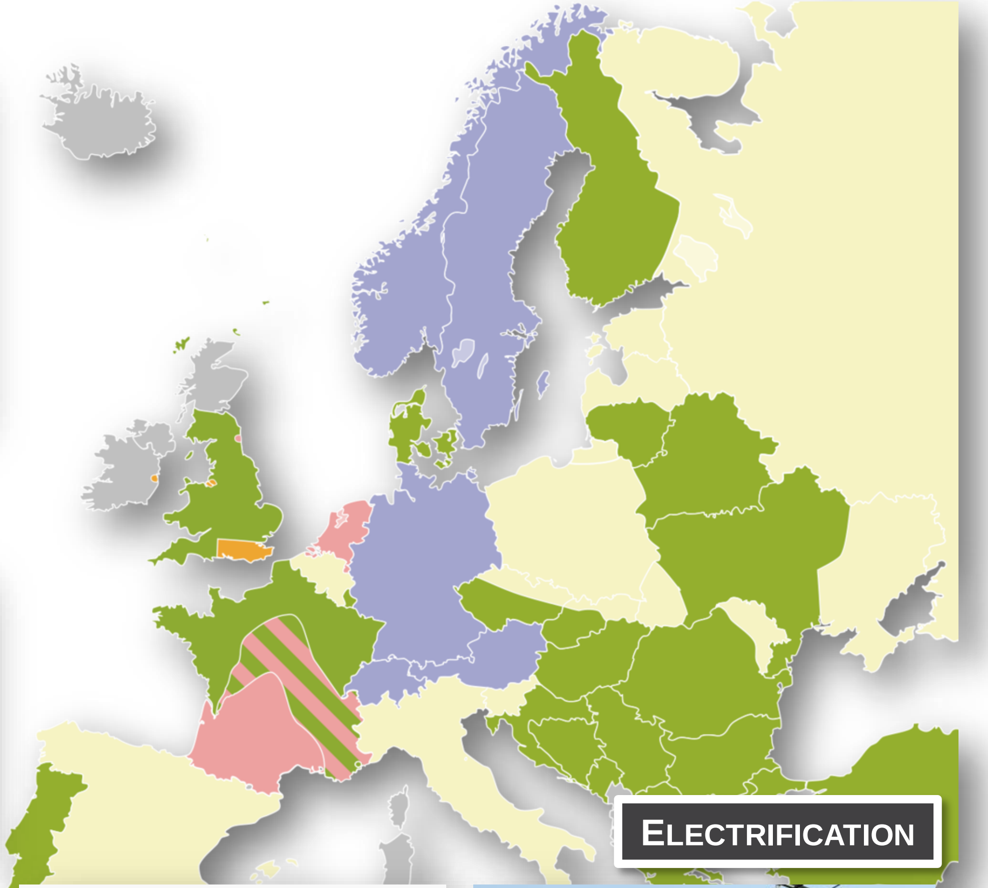
International Best Practice Analysis

Trans European High-Speed Rail System – Integration Challenges

Structure Gauges



Track Gauges



Electrification

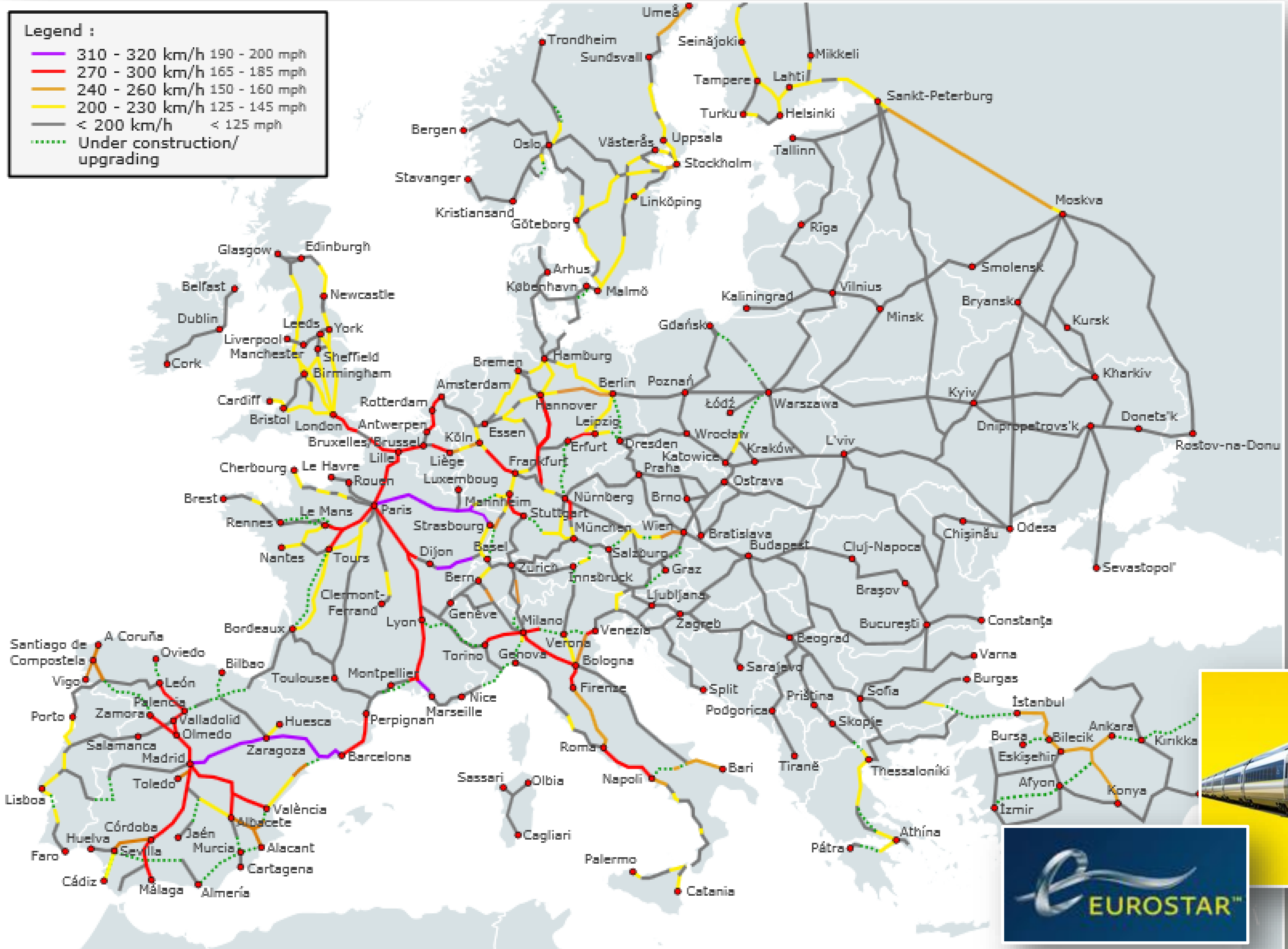
Electrification systems:

- 750 V DC
- 1,5 kV DC
- 3 kV DC
- 15 kV, 16.7 Hz AC
- 25 kV, 50 Hz AC
- Non-electrified

se.org/symp2020

International Best Practice Analysis

Technical Specifications for Interoperability (TSI)

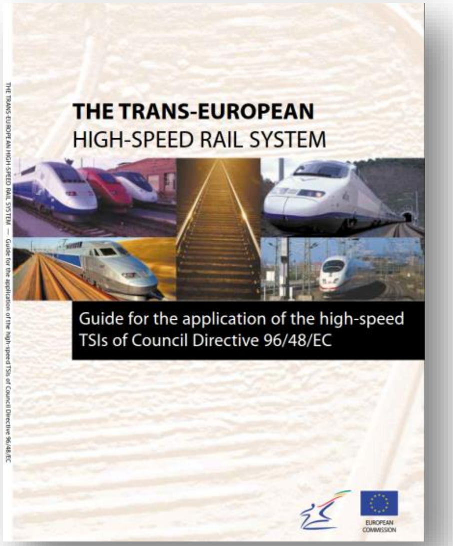


Technical Specifications for Interoperability (TSI)

EUROSTAR™

International Best Practice Analysis

TSIs – Subsystems & Interfaces



8 Subsystems, incl. 4 Structural Subsystems:

1. Infrastructure
2. Energy
3. Control-Command & Signalling
4. Rolling Stock

4.3 Functional and technical specification of the interfaces

From the standpoint of technical compatibility, the interfaces of the infrastructure domain with the other subsystems are the following:

4.3.1 Interfaces with the rolling stock subsystem

Interfaces between Infrastructure & Rolling Stock

Interface	Reference High-Speed Infrastructure TSI	Reference High-speed Rolling Stock TSI
Structure gauge Infrastructure gauge	4.2.3 minimum infrastructure gauge	4.2.3.1 kinematic gauge 4.2.3.3. Rolling stock parameters, which influence ground based train monitoring systems
gradients	4.2.5 maximum rising and falling gradients	4.2.3.6 maximum gradients 4.2.4.7 Bra[illegible]ce on st[illegible]
Minimum radius	4.2[illegible]a- 4.2.[illegible] deficiency	4.2.3.7 M[illegible] radius
Equivalent conicity	4.2.9 equivalent conicity 4.2.11 rail inclination 5.3.1.1 railhead profile	4.2.3.4 Rolling stock dynamic behaviour; 4.2.3.4.7 design values for wheel profiles

Specific Interfaces

Infrastructure Subsystem TSI

International Best Practice Analysis

TSIs – Interoperable Interface Specification

Infrastructure (INF) Subsystem

4.2.3 Minimum infrastructure gauge — **Infrastructure**

The infrastructure must be constructed so as to allow safe clearance for the passage of trains complying with the High-Speed Rolling Stock TSI.

Minimum infrastructure gauge is defined by given swept volume inside which no obstacle must be located or intrude. This volume is determined on the basis of a reference kinematic profile and takes into account the gauge of catenary and the gauge for lower parts.

The relevant kinematic profiles are specified in the High-Speed Rolling Stock TSI.

…elating to gauges, the Infrastructure Manager … infrastructure gauge.

Interface	Reference High-Speed Infrastructure TSI	Reference High-speed Rolling Stock TSI
Structure gauge Infrastructure gauge	4.2.3 minimum infrastructure gauge	4.2.3.1 kinematic gauge 4.2.3.3. Rolling stock parameters, … systems
Interoperable Interface	**Reference INF TSI**	**Reference RST TSI**

Rolling Stock (RST) Subsystem

4.2.3.1. Kinematic gauge — **Trainsets**

Rolling stock shall comply with one of the kinematic vehicle gauges defined in Annex C of the Conventional Rail Rolling Stock Freight Wagon TSI 2005.

Interoperable Standard(s)

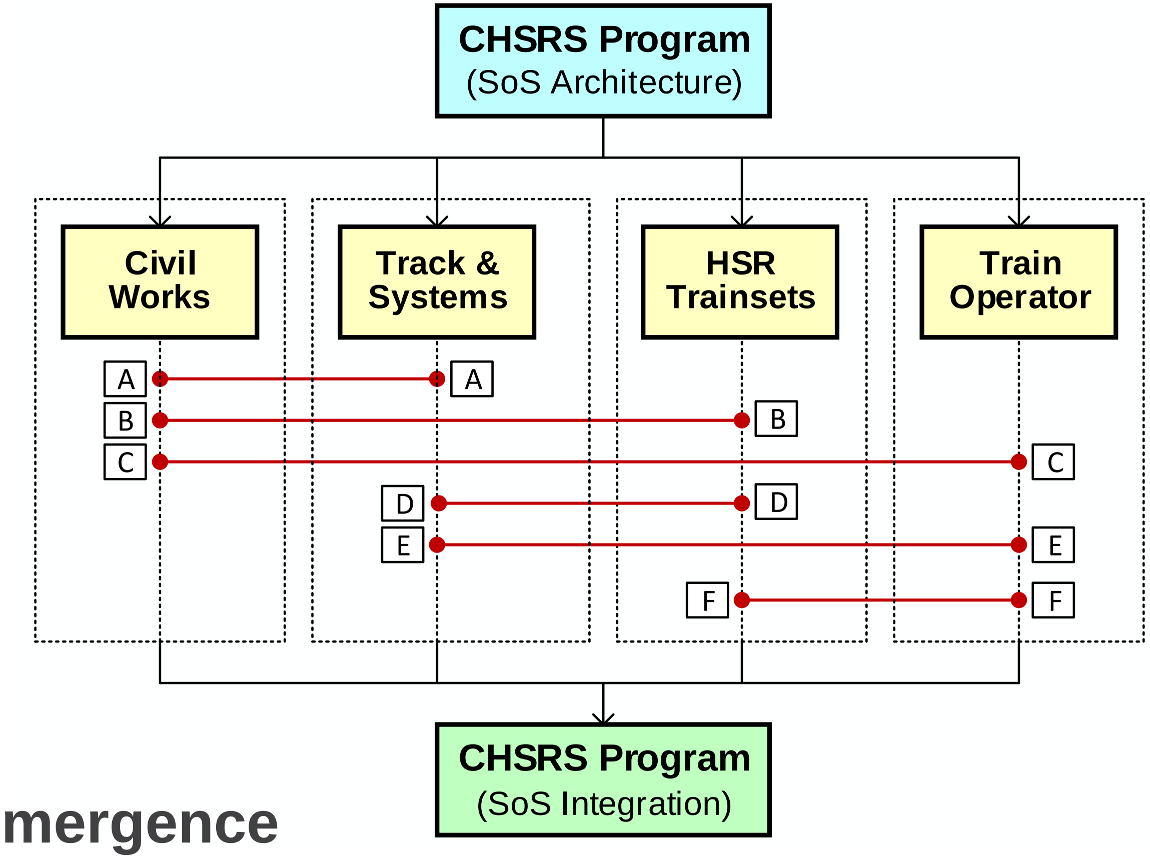
The pantograph gauge shall comply with Clause 5.2 of prEN 50367:2006

The type or design examination certificate of 'EC' verification of the rolling stock and the rolling stock register shall indicate the assessed gauge.

SoS Integration Strategy

Interoperability Approach

- **SoS Leadership & Authority**
  - Leadership: CHSRS system integration team
  - Authority: Integration team authorized to identify & manage technical Interfaces
- **SoS Architecture**
  - SoS: CHSRS program
  - Constituent systems: CHSRS projects
- **SoS Collaboration & Integration**
  - SoS: Interface identification & specification
  - Constituent systems: Interface implementation
- **SoS Autonomous Constituent Systems & Emergence**
  - SoS: Defines interoperable interface standards
  - Constituent systems: Allowed innovate, emergent solutions …
  - … as long as they meet interoperable interfaces standards



SoS Integration Strategy

Seven (7) Step Process

Step 1: SoS architect (systems integration team) identifies key interfaces

Step 2: HSR trainset subject matter expert (SME) identifies candidate HSR trainsets

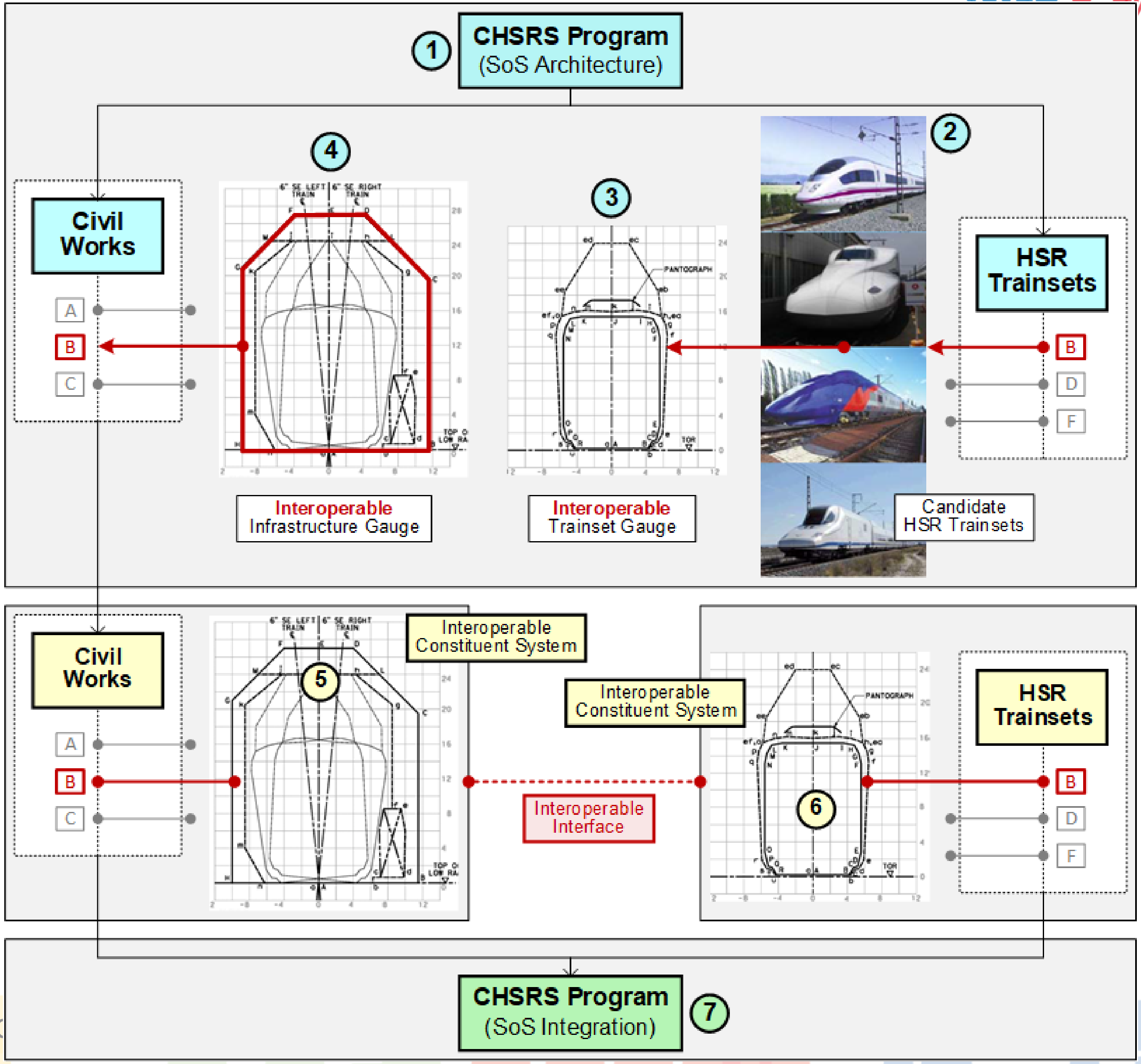
Step 3: HSR trainset SME determines interoperable interface requirements

Step 4: Civil works SME develops corresponding interoperable interface design

Step 5: Civil works contractor implements interoperable civil works contract

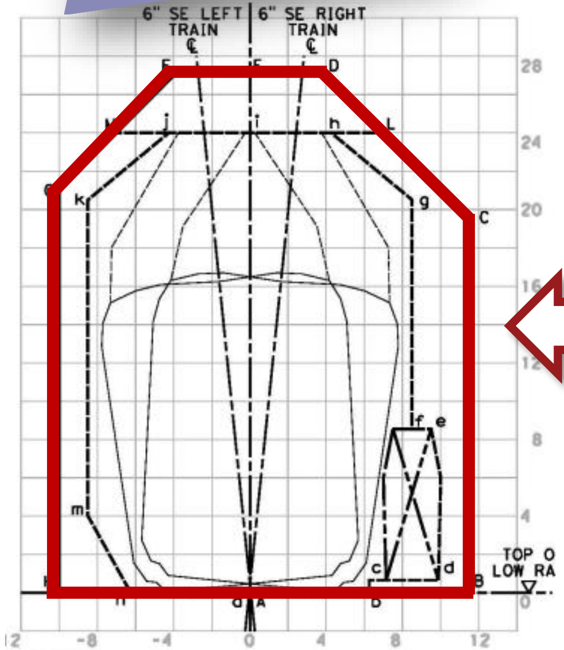
Step 6: HSR trainset contractor implements interoperable HSR trainset contract

Step 7: SoS system integrator (track & systems contractor) integrates, tests, and commissions (taking into service) the interoperable contracts

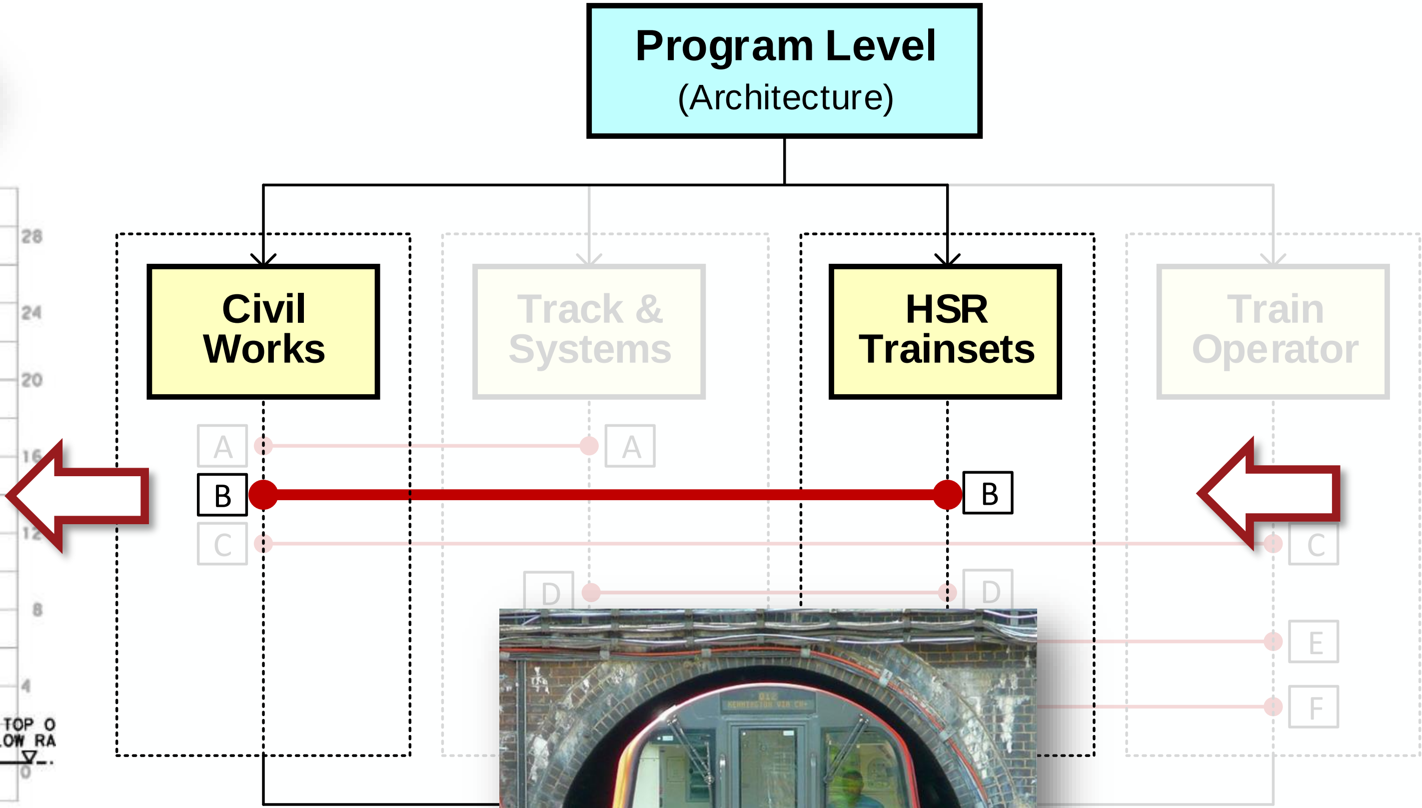


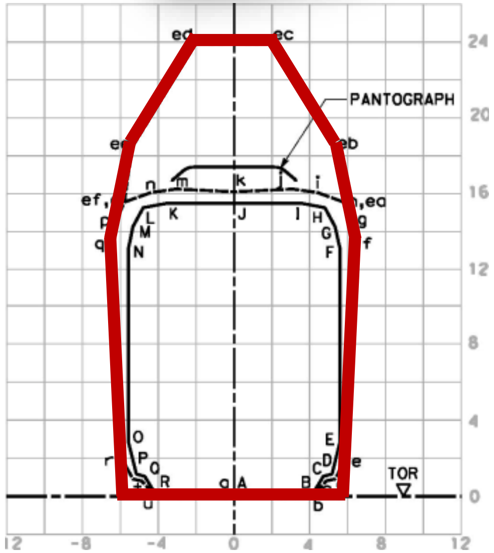
STEP 1: IDENTIFICATION OF KEY INTERFACES

EXAMPLE: INTERFACE BETWEEN TRAINSET ENVELOPE & INFRASTRUCTURE GAUGE



INFRASTRUCTURE GAUGES





TRAINSET ENVELOPES

Step 1: Identification of Key Interfaces

TSI Interface Analysis, Application & Tailoring to CHSRS

Interfaces between Infrastructure & Rolling Stock

_TSI-TYPE			Traced To: IF-REG (LM)
---	1 TSI Interface Register		
---	1.1 TSI Infrastructure		
---	1.1.1 Interfaces with the Rolling Stock Subsystem		
---	1.1.1.1 Structure Gauge and Infrastructure Gauge		
INF_A RST	1.1.1.1.1 Interface between INF Minimum Infrastructure Gauge and RST Kinematic Gauge TSI INF_A: Interface: Structure gauge • TSI INF: 4.2.3 Minimum • TSI RST: 4.2.3.1 Kinematic gauge TSI RST: Clause 4.2.3.1 of this TSI specifies that the rolling stock shall comply with one of the kinematic vehicle gauges that are specified in Annex C of the Conventional Rail Rolling Stock TSI 2005. The corresponding infrastructure gauges are specified in clause 4.2.3 of the Infrastructure TSI 2006, and the infrastructure register states for each line the kinematic gauge that shall be met by the rolling stock operating on this line.	[10 TSI-INF_A] ID: 30 4.2.3 Minimum infrastructure gauge (INF-3-03: Minimum Infrastructure Clearances) [10 TSI-INF_A] ID: 168 4.3.1 Interfaces with the rolling stock subsystem [30 TSI-RST] ID: 77 4.2.3.1 Kinematic gauge (RST-5-03.1: Kinematic gauge) [30 TSI-RST] ID: 398 4.3.2.3 Kinematic gauge	[IF-REG] ID: 481 Interface between RST HST Trainset Dynamic Envelope Requirements and GWY Infrastructure [IF-REG] ID: 490 Interface between RST HST Trainset Static Gauge Requirements and GWY Infrastructure
	1.1.1.1.2 Interface between INF Minimum Infrastructure Gauge and RST Rolling Stock Parameters which influence Ground Based Train Monitoring Systems TSI INF_A: Interface: Structure gauge, Infrastructure gauge • TSI INF: 4.2.3 Minimum infrastructure gauge • TSI RST: 4.2.3.3. Rolling stock parameters, which influe monitoring systems TSI RST: Clause 4.2.3.3.2 of this TSI details the specifications concerning the rolling stock related to axle bearing health monitoring by trackside hot axle boxes detectors. The minimum infrastructure gauge requirements concerning the infrastructure subsystem are set out in clause 4.2.3 of the Infrastructure TSI 2006. Clause 4.2.3.3.2.3 of this TSI details the specifications concerning the rolling stock related to parameters, which influence ground based train monitoring systems, and particularly electrical resistance of the wheelsets and axle bearing health monitoring. The corresponding specifications concerning the control-command and signalling subsystem are set out in clauses 4.2.10 and 4.2.11 of the Control-Command and Signalling TSI 2006 and in its Annex A Appendix 1 clauses 1 to 4.	[10 TSI-INF_A] ID: 30 4.2.3 Minimum infrastructure gauge (INF-3-03: Minimum Infrastructure Clearances) [30 TSI-RST] ID: 85 4.2.3.3.2.1 Class 1 trains (RST-5-03.3: Rolling stock parameters which influence ground based train monitoring systems) [30 TSI-RST] ID: 87 4.2.3.3.2.2 Class 2 trains (RST-5-03.3: Rolling stock parameters which influence ground based train monitoring systems) [30 TSI-RST] ID: 90 4.2.3.3.2.3.1 General (RST-5-03.3: Rolling stock parameters which	[IF-REG] ID: 600 Interface between SYS COM Wayside/Field Equipment Spatial Requirements and GWY Infrastructure S TCS Wayside/Field quirements and GWY Interface between SYS TCS Wayside Train Detection System and RST HST Trainset Wheelset Electrical Resistance [IF-REG] ID: 6341 Interface between SYS TCS Wayside Hazard Detection System and RST HST Trainset Axle Bearing Health Monitoring

Specific Interfaces

Tailored CHSRS Interfaces

Tailoring: 49 TSI infrastructure interfaces resulted in over 100 CHSRS guideway (GWY) infrastructure interfaces

Technical Specifications for Interoperability (TSI)

STEP 1: IDENTIFICATION OF KEY INTERFACES

INTERFACE REGISTER USING N^2 CHART APPROACH

ID	_TSI-TYPE		Traced To: IF-REG (LM)
1	---	1 TSI Interface Register	
5	---	1.1 TSI Infrastructure	
2	---	1.1.1 Interfaces with the Rolling Stock Subsystem	
3	---	1.1.1.1 Structure Gauge and Infrastructure Gauge	
4	INF_A RST	1.1.1.1.1 Interface between INF Minimum Infrastructure Gauge and RST Kinematic Gauge TSI INF_A: Interface: Structure gauge, Infrastructure gauge • TSI INF: 4.2.3 Minimum infrastructure gauge • TSI RST: 4.2.3.1 Kinematic gauge TSI RST: Clause 4.2.3.1 of this TSI specifies that the rolling stock shall comply with one of the kinematic vehicle gauges that are specified in Annex C of the Conventional Rail Rolling Stock TSI 2005. The corresponding infrastructure gauges are specified in clause 4.2.3 of the Infrastructure TSI 2006, and the infrastructure register states for each line the kinematic gauge that shall be met by the rolling stock operating on this line.	[IF-REG] ID: 481 Interface between RST HST Trainset Dynamic Envelope Requirements and GWY Infrastructure [IF-REG] ID: 490 Interface between RST HST Trainset Static Gauge Requirements and GWY Infrastructure
13	---	1.5 TSI Energy	
108	---	1.5.1 Interfaces with the Rolling Stock Subsystem	
113	---	1.5.1.1 Voltage and Frequency	
130	RST EGY	1.5.1.1.1 Interface between EGY Voltage and Frequency and RST Energy Supply TSI EGY: Interface: Voltage and frequency & Energy Supply • TSI EGY: 4.2.2 • TSI RST: 4.2.8.3.1.1 TSI RST: Clause 4.2.8.3 of this TSI details the specifications concerning the rolling stock related to power supply. The corresponding specifications concerning the energy subsystem are specified in clauses 4.2.2, ... of the Energy TSI 2006. The specifications concerning the energy subsystem, related to the position of [illegible] 2006.	[IF-REG] ID: 6408 Interface between TRK TP Voltage and Frequency and RST HST Trainset
14	---	1.6 TSI Operations and Traffic Management	
244	---	1.6.3 Interfaces with the Rolling Stock TSI	
248	---	1.6.3.1 Braking	
272	RST OPE	1.6.3.1.1 Interface between OPE Brake Performance and RST Brake System Requirements TSI OPE: Interfaces exists between Subsection 4.2.2.5.1, 4.2.2.6.1 and 4.2.2.6.2 of this OPE TSI, and subsection 4.2.4.1 and 4.2.4.3 of the HS RST TSI. TSI RST:	[IF-REG] ID: 6672 Interface between O&M OPS Brake Performance Requirements and RST HST Trainset Brake System Performance

INTERFACES BETWEEN INFRASTRUCTURE & ROLLING STOCK

INTERFACES BETWEEN ENERGY & ROLLING STOCK

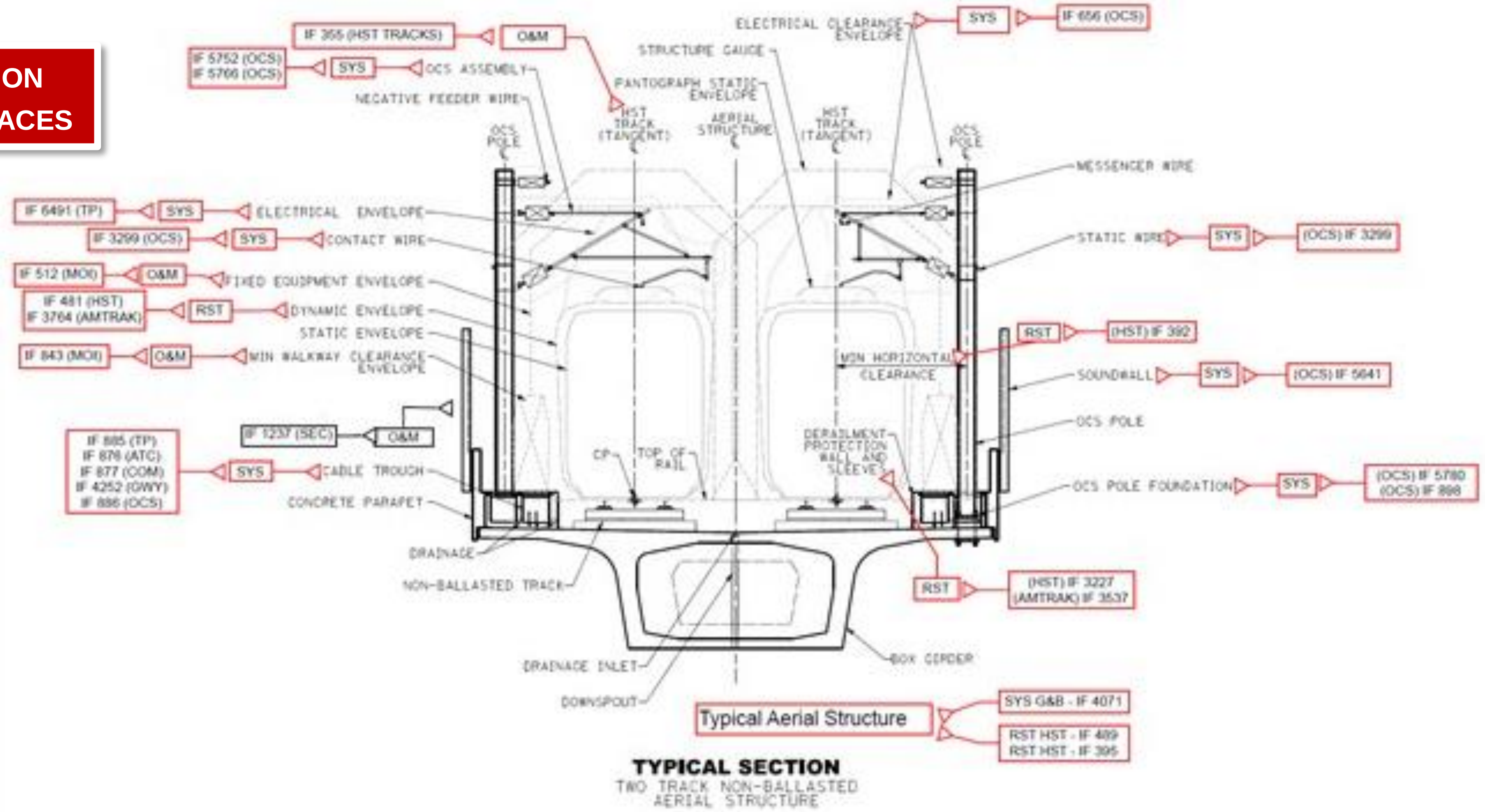
INTERFACES BETWEEN OPERATIONS & ROLLING STOCK

Step 1: Identification of Key Interfaces

Integrated Cross Sections: Example Aerial Structure

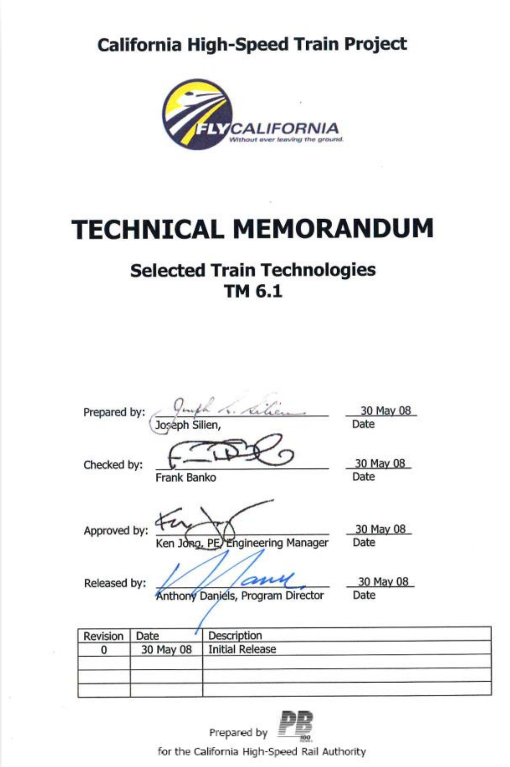
Improve Visibility, Recognition and Communication of Interfaces

Cedar Viaduct



Aerial Structure Integrated Cross Section

Step 2: Identify Candidate HSR Solutions



California High-Speed Train Project

FLY CALIFORNIA
Without ever leaving the ground.

TECHNICAL MEMORANDUM

Selected Train Technologies
TM 6.1

Prepared by:	Joseph Silien,	30 May 08	Date
Checked by:	Frank Banko	30 May 08	Date
Approved by:	Ken Jong, PE, Engineering Manager	30 May 08	Date
Released by:	Anthony Daniels, Program Director	30 May 08	Date

Revision	Date	Description
0	30 May 08	Initial Release

Prepared by PB for the California High-Speed Rail Authority

Selected Train Technologies

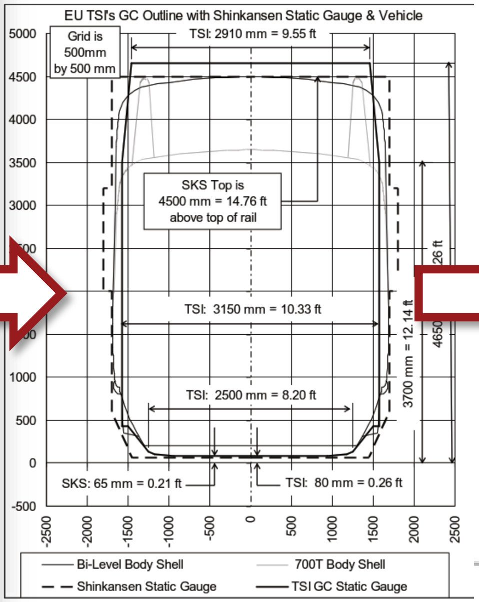
Model		Builder	Year Built	AW0 [UST]	Produced	Consist	Seats	Country	Length (m)	Width [m]	Train Length [m]	Height [m]	Maximum Operating Speed [kph]	Weigh [tonne
		Siemens	2004	467	26 Trainsets	MCC-TC-MC-2TC-MC-TC-MCC	404	Spain	25.67 CC 24.77 C	2.95	200	3.89	350	425/T
		Hitachi/Kawasaki/ Nippon Sharyo	2005~	769	97 Trainsets by 2011	TCC-14MC-TCC	1323	Japan	25 C 27.35 CC	3.36	430.6	3.6 or 3.5	300	40/C
		Alstom	2008	270 to 510	1 Prototype	7C~14C	250~650	France	17.1 CC 17.3 C	2.9	130~250	/	360	270~51
AVE S-102Power Car (S-350 Trainset)		Bombardier	2004	92 Max. (Loco Only)	46	1L-12C-1L	318	Spain	20.87 L	2.96	366	4	330	Max 17t/Axl

Review of over 30 commercially available HSR trainsets operated in China, France, Germany, Italy, Korea, Japan, Russia, Spain, Taiwan, and the U.S.

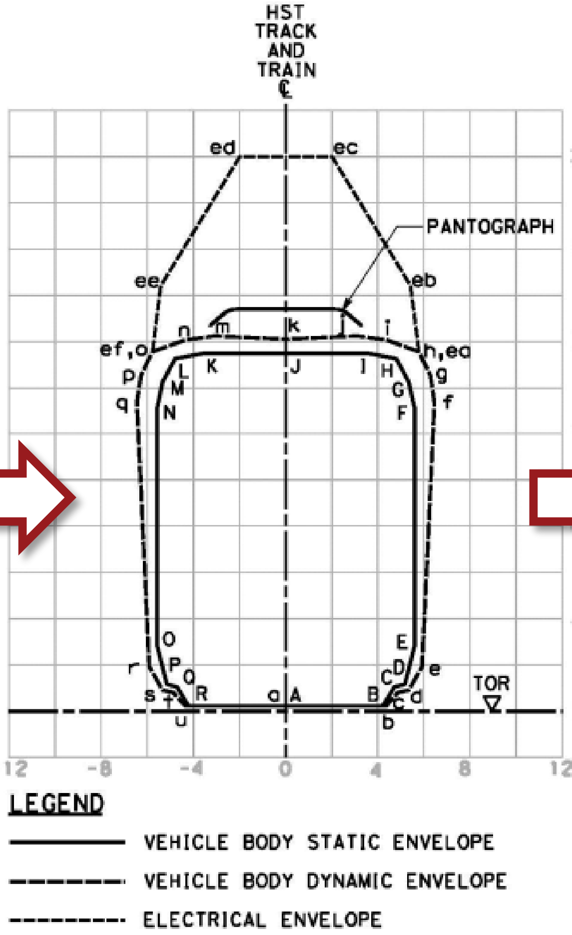
Step 3/4: Develop Interoperable Interface Standard

Candidate HSR Trainsets

Figure 3.1.4: EU TSI Static Gauges GC Compared with Shinkansen Gauge

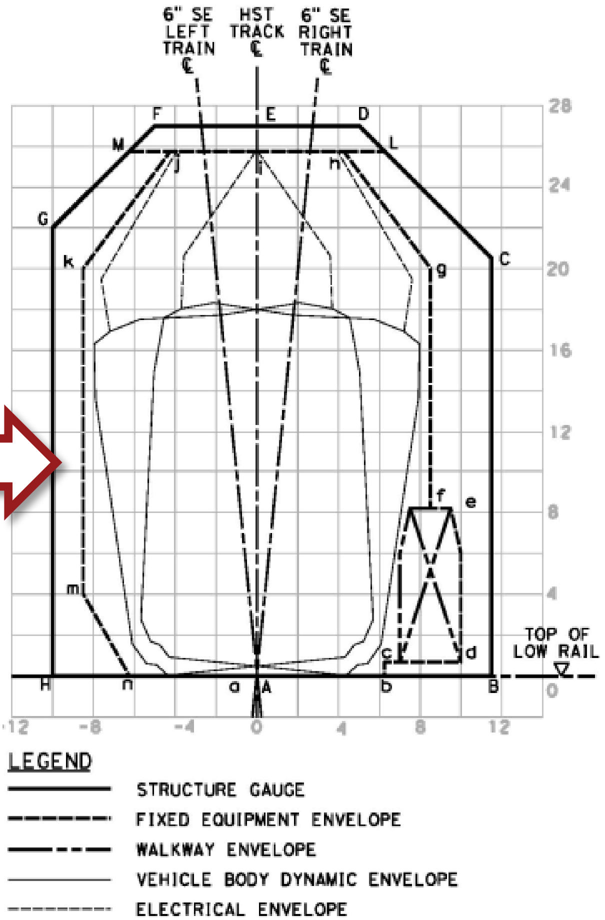


Overlaid Trainset Envelopes



Interoperable Trainset Envelopes

Appendix 3.G: All Passenger Equipment, Structure Gauge and Fixed Equipment Envelope, Open Sections



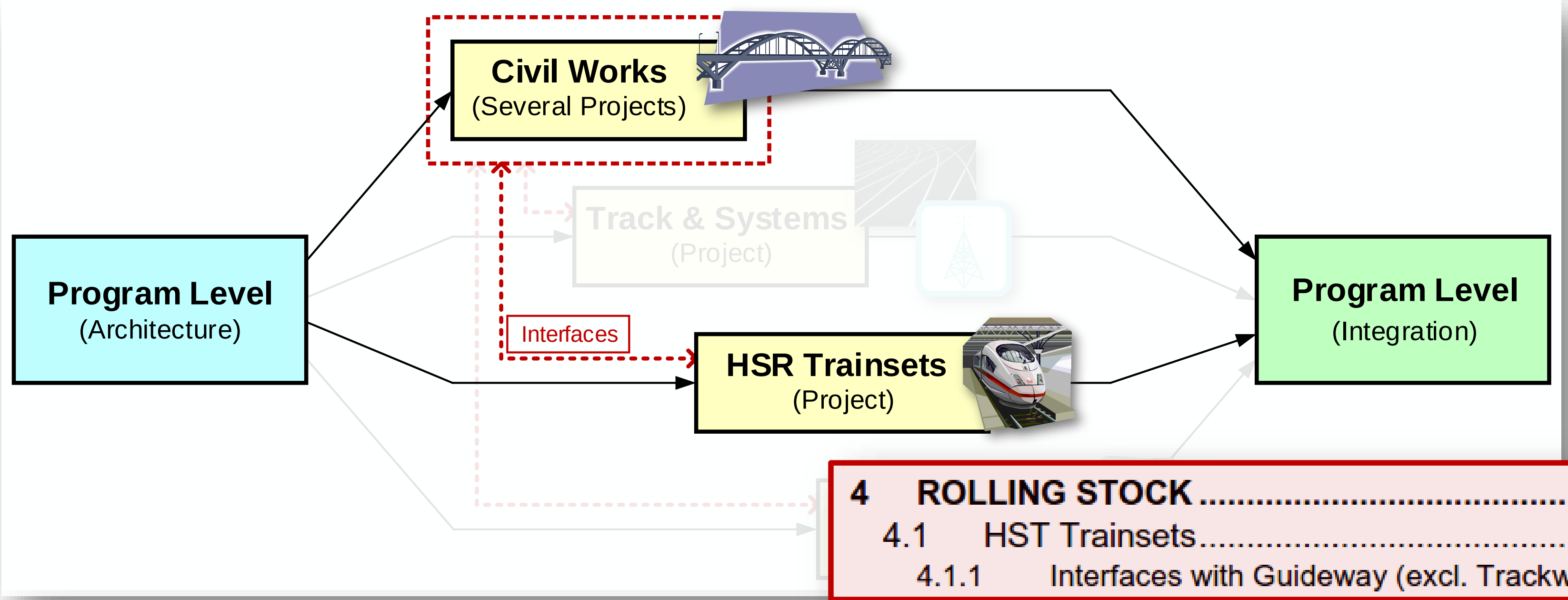
Interoperable Structure Gauges

Point ID	Horizontal Distance from TCL (feet)	Vertical Distance from TOR (feet)
Open Sections		
Structure Gauge		
Walkway Side (See Note 3 & 4)		
A	0.00	0.00
B	11.50	0.00
C	11.50	20.50
D	5.00	27.00
E	0.00	27.00
Non-Walkway Side		
A	0.00	0.00
H	-10.00	0.00
G	-10.00	20.50
F	-5.00	27.00
E	0.00	27.00
Under Existing Low Overhead Structures		
L	6.25	25.75
M	-6.25	25.75
Fixed Equipment Envelope		
Walkway Side (See Notes 1, 3, & 4)		
a	0.00	0.00
b	6.25	0.00
c	6.25	0.67
d	10.00	0.67
e	10.00	8.17
f	8.50	8.17
g	8.50	20.00
h	4.25	25.75
i	0.00	25.75
Non-Walkway Side		
a	0.00	0.00
n	-6.25	0.00
m	-8.50	4.00
k	-8.50	20.00
j	-4.25	25.75

Civil Works Design Criteria

Step 5: Civil Works Implementation

Communication of Interfaces & Interface Standards to Contractors

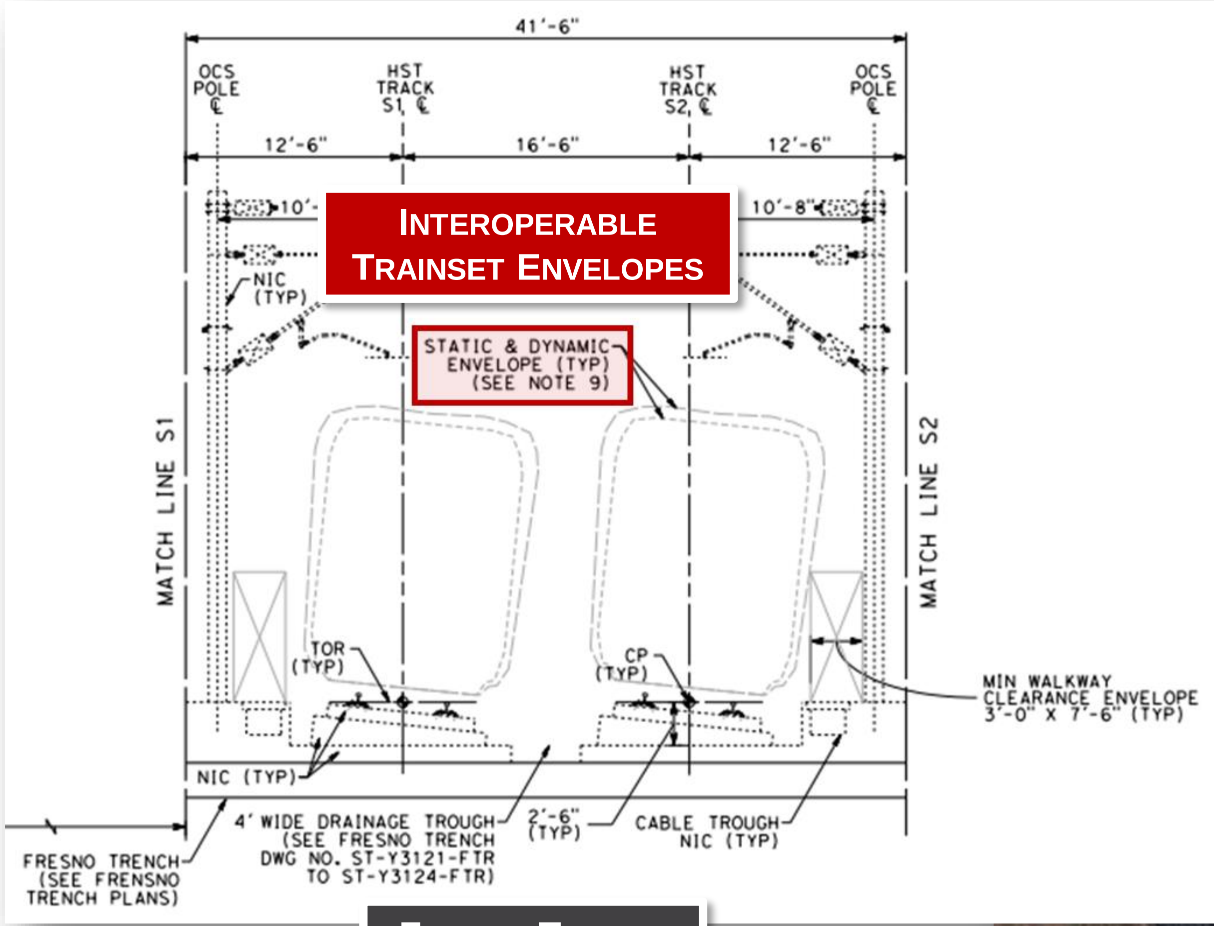


Imposed CHSRS Interfaces using N^2 Chart Approach

List of Interfaces Provided to Civil Works Including References to Design Criteria

Step 5: Civil Works Implementation

Contractor Final Design & Construction



Fresno Trench
Final Design

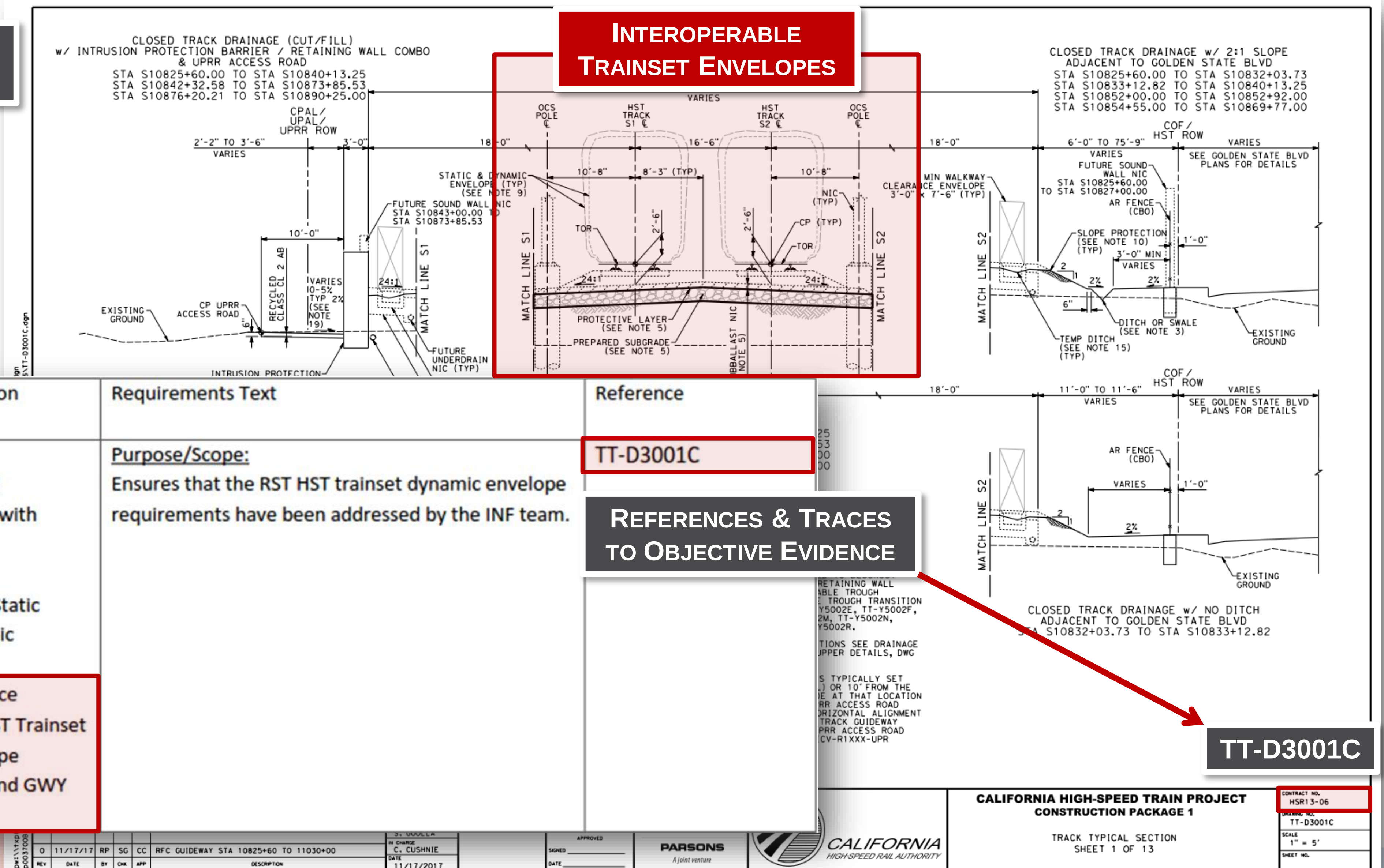
Fresno Trench
Construction

Step 5: Civil Works Implementation

Trust But Verify (CHSRS Verification & Validation Process)

Contractor Design Submittal

Interoperable Trainset Envelopes



Interface Traceability (Certifiable Items List)

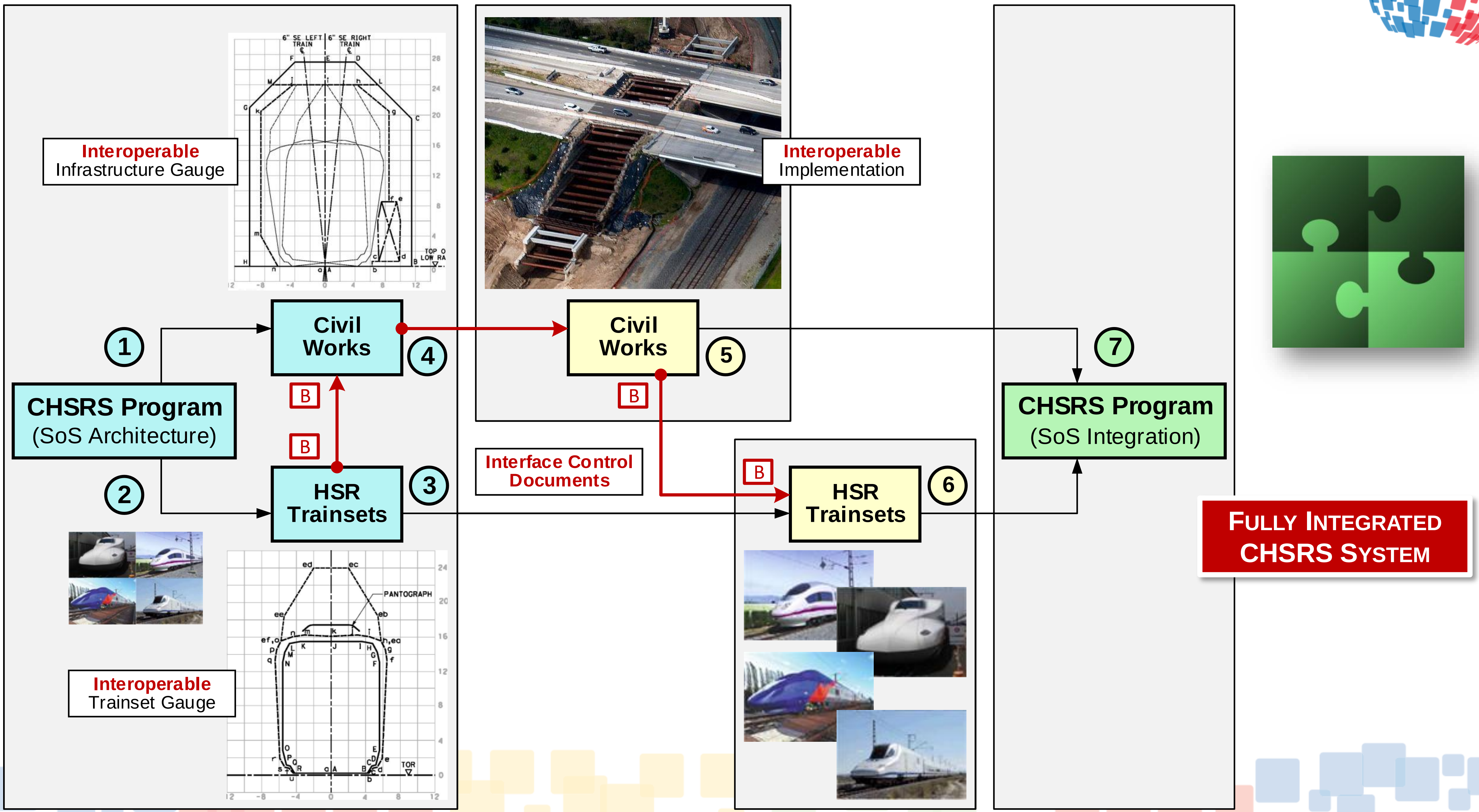
ID	DOC ID	CIL-Safety	Document Section	Requirements Text	Reference
71	Interoperability	CHSRIR329 (IF 481)	4 Rolling Stock 4.1 HST Trainset 4.1.1 Interfaces with Guideway (excl. [illegible]work) [illegible].2 Vehicle Static Gauge & Dynamic Envelope 4.1.1.2.2 Interface between RST HST Trainset Dynamic Envelope Requirements and GWY Infrastructure	Purpose/Scope: Ensures that the RST HST trainset dynamic envelope requirements have been addressed by the INF team.	TT-D3001C

Interoperable CHSRS Interface

References & Traces to Objective Evidence

TT-D3001C

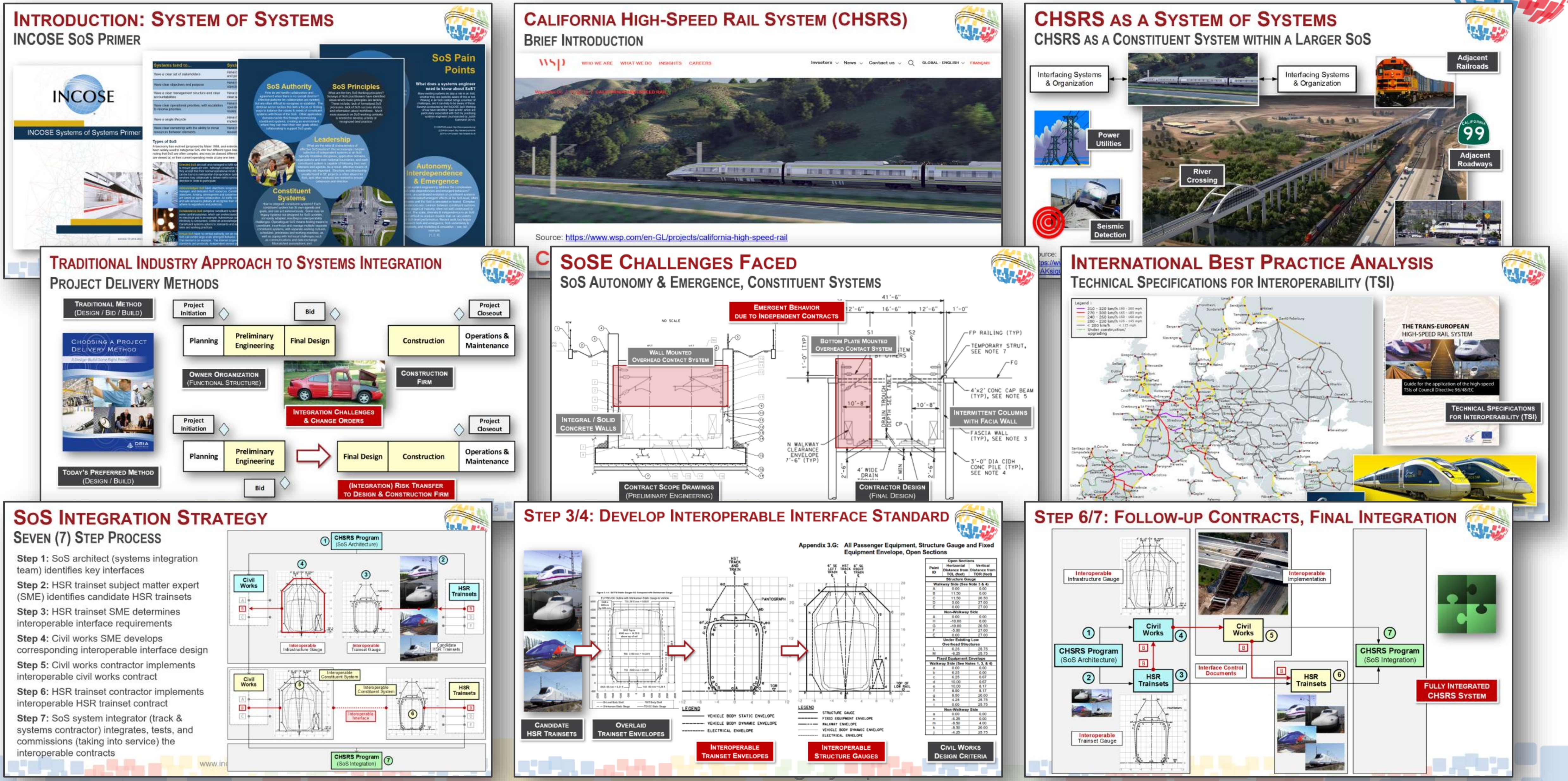
Step 6/7: Follow-up Contracts, Final Integration



PROGRESS

- **Introduction**
  - System of Systems (SoS)
  - California High-Speed Rail System (CHSRS) Program
  - CHSRS as a System of Systems
- **SoSE Challenges Faced**
  - Traditional Industry Approach to Systems Integration
  - SoS Engineering Challenges
- **SoSE Activities Performed**
  - International Best Practice Analysis of HSR System Integration
  - SoS Integration Strategy
  - Step by Step Process Description
- **Summary, Achieved Outcomes & Conclusion**

SUMMARY



INTRODUCTION: SYSTEM OF SYSTEMS
INCOSE SOS PRIMER
INCOSE
INCOSE Systems of Systems Primer
SoS Pain Points
SoS Authority
SoS Principles
Leadership
Constituent Systems
Autonomy, Interdependence & Emergence
CALIFORNIA HIGH-SPEED RAIL SYSTEM (CHSRS)
BRIEF INTRODUCTION
Source: https://www.wsp.com/en-GL/projects/california-high-speed-rail
CHSRS AS A SYSTEM OF SYSTEMS
CHSRS AS A CONSTITUENT SYSTEM WITHIN A LARGER SOS
Interfacing Systems & Organization
Interfacing Systems & Organization
Adjacent Railroads
Power Utilities
99
Adjacent Roadways
River Crossing
Seismic Detection
TRADITIONAL INDUSTRY APPROACH TO SYSTEMS INTEGRATION
PROJECT DELIVERY METHODS
TRADITIONAL METHOD (DESIGN / BID / BUILD)
Project Initiation
Bid
Project Closeout
Planning
Preliminary Engineering
Final Design
Construction
Operations & Maintenance
OWNER ORGANIZATION (FUNCTIONAL STRUCTURE)
CONSTRUCTION FIRM
INTEGRATION CHALLENGES & CHANGE ORDERS
CHOOSING A PROJECT DELIVERY METHOD
TODAY'S PREFERRED METHOD (DESIGN / BUILD)
Project Initiation
Project Closeout
Planning
Preliminary Engineering
Final Design
Construction
Operations & Maintenance
Bid
(INTEGRATION) RISK TRANSFER TO DESIGN & CONSTRUCTION FIRM
SOSE CHALLENGES FACED
SOS AUTONOMY & EMERGENCE, CONSTITUENT SYSTEMS
EMERGENT BEHAVIOR DUE TO INDEPENDENT CONTRACTS
WALL MOUNTED OVERHEAD CONTACT SYSTEM
BOTTOM PLATE MOUNTED OVERHEAD CONTACT SYSTEM
INTEGRAL / SOLID CONCRETE WALLS
INTERMITTENT COLUMNS WITH FACIA WALL
CONTRACT SCOPE DRAWINGS (PRELIMINARY ENGINEERING)
CONTRACTOR DESIGN (FINAL DESIGN)
INTERNATIONAL BEST PRACTICE ANALYSIS
TECHNICAL SPECIFICATIONS FOR INTEROPERABILITY (TSI)
THE TRANS-EUROPEAN HIGH-SPEED RAIL SYSTEM
TECHNICAL SPECIFICATIONS FOR INTEROPERABILITY (TSI)
SOS INTEGRATION STRATEGY
SEVEN (7) STEP PROCESS
Step 1: SoS architect (systems integration team) identifies key interfaces
Step 2: HSR trainset subject matter expert (SME) identifies candidate HSR trainsets
Step 3: HSR trainset SME determines interoperable interface requirements
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CHSRS Program (SoS Architecture)
Civil Works
HSR Trainsets
Interoperable Infrastructure Gauge
Interoperable Trainset Gauge
Candidate HSR Trainsets
CHSRS Program (SoS Integration)
STEP 3/4: DEVELOP INTEROPERABLE INTERFACE STANDARD
Appendix 3.G: All Passenger Equipment, Structure Gauge and Fixed Equipment Envelope, Open Sections
CANDIDATE HSR TRAINSETS
OVERLAID TRAINSET ENVELOPES
INTEROPERABLE TRAINSET ENVELOPES
INTEROPERABLE STRUCTURE GAUGES
CIVIL WORKS DESIGN CRITERIA
STEP 6/7: FOLLOW-UP CONTRACTS, FINAL INTEGRATION
Interoperable Infrastructure Gauge
Interoperable Implementation
Civil Works
Civil Works
CHSRS Program (SoS Architecture)
HSR Trainsets
Interface Control Documents
HSR Trainsets
CHSRS Program (SoS Integration)
FULLY INTEGRATED CHSRS SYSTEM
Interoperable Trainset Gauge

ACHIEVED OUTCOMES & CONCLUSION

- **SoS Authority & Leadership**
  - Maximized limited SoS authority by focusing on technical systems integration
  - Demonstrated SoS leadership by developing tailored SoS integration strategy based on proven internal best practices
- **SoS Architecture**
  - Developed SoS architecture based on procurement strategy with program as SoS and procurement contracts (projects) serving as constituent systems
  - Created easily understandable SoS architecture with key stakeholder buy-in
- **SoS Collaboration & Integration**
  - Worked closely with subject matter experts to communicate, specify and document key interfaces between the procurement contracts
- **SoS Autonomous Constituent Systems & Emergence**
  - Enabled individual Design / Build contract innovation and SoS emergence, without negatively affecting overall SoS integration
- **Conclusion:** The tailored CHSRS systems integration approach created modular and interoperable constituent systems that can be efficiently integrated into a SoS, successfully **achieving system integration through interoperability**

30th Annual INCOSE international symposium

Virtual Event

July 20 - 22, 2020

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