ONE-ITS2.0: Automating Multi-Stakeholder ITS Cyber-Physical Service Integration in the Internet of Everything Context

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Outline

- Background and Motivation
- A Three-Pillar Framework to Support Seamless Coordination of Cyber-Physical ITS
  - Integrated Service Execution (ISE)
  - Integrated Service Planning (ISP)
  - Ontological Semantic Knowledge Representation (OSKR)
- A Proof-of-Concept ATIS Prototype
- Conclusions
Research Objectives
Intelligent Transportation System of Systems (ITSoS)

- To avoid the need to design, implement, and maintain large and complex regional monolithic systems.
  - Support greater connectivity and convergence of existing ITS sensors, services, and applications in the context of Internet of Things (IoT). *(Semantic interoperability)*
  - Facilitates collaboration and coordination across transportation stakeholders to design regional ITS plans. *(Coordinated Planning)*
  - Facilitates dynamic execution of ITS Plans to achieve stakeholders’ common objectives. *(Automatic Integration)*
Monolithic systems vs SoS
Key SoS Characteristics (Maier, 1998)

- Operational Independence of the SoS elements
- Managerial Independence of the SoS elements
- Evolutionary Development
- Emergent Behavior
- Geographic Distribution
Motivational Example

Available Services Information on travel, for their use.

Current Situation Information on transportation systems.

PTTI shall include a Trip Planning Service.

Current status of any accidents or incidents.

Current parking conditions in key areas.

Current speeds on specific routes.

Current condition of any road construction.

Any currently recommended alternate routes.
A Three-Pillar Framework to Support Seamless Coordination of Cyber-Physical ITS

1. Ontological Semantic Knowledge Representation (OSKR)
   - Ontology for Abstract ITS Operations (OITSP)
   - Web Services (OWL-S)
   - Sensors (SSN)
   - Infrastructure (OTN)

2. Integrated Service Planning (ISP)
   - Needs and Scope
   - Functional Requirements
   - Terminators
   - Interfaces
   - Hierarchical Tasks

3. Integrated Service Execution (ISE)
   - ITSoS Composer
   - Service Discovery
   - Service Invocation
   - Context Management
   - ONE-ITS Portal
Integrated Service Execution (ISE)
Integrated Service Execution (ISE)

Supports creating, sending, and receiving messages
Integrated Service Execution (ISE)

Service Orchestration (Discovery & Composition)

ITSoS Composer

Messaging Infrastructure

Sensor 1  Sensor m  Service 1  Service n
Integrated Service Execution (ISE)

Service registry, monitoring, and invocation

ITSoS Composer

Service Management

Data Mapping /Transformation

Messaging Infrastructure

Sensor 1
Sensor m
Service 1
Service n
Integrated Service Execution (ISE)

Context gathering, processing, and dispatch

ITSoS Composer

Context Management

Service Management

Data Mapping / Transformation

Messaging Infrastructure

Sensor 1

Sensor m

Service 1

Service n
Integrated Service Execution (ISE)

- Allows end users to send requests and receive responses

**Portal**

**ITSoS Composer**

- **Context Management**
- **Service Management**

**Data Mapping /Transformation**

**Messaging Infrastructure**

- **Sensor 1**
- **Sensor m**
- **Service 1**
- **Service n**
Integrated Service Execution (ISE)

A common language among all the modules

- Portal
- ITSoS Composer
- Service Management
- Data Mapping/Transformation
- Messaging Infrastructure

- Sensor 1
- Sensor m
- Service 1
- Service n

Ontological Model
Integrated Service Planning (ISP)

1) Identify Needs and Scope
2) Determine Key Services and Functional Requirements
3) Define Terminators and Interfaces
4) Develop an Operational Procedure (Task Network Definition)
Integrated Service Planning (ISP)

Concerned Stakeholders
Overall Goals
Geographic Boundaries
Timeframe

1) Identify Needs and Scope
2) Determine Key Services and Functional Requirements
3) Define Terminators and Interfaces
4) Develop an Operational Procedure (Task Network Definition)
Integrated Service Planning (ISP)

1) Identify Needs and Scope
2) Determine Key Services and Functional Requirements
3) Define Terminators and Interfaces
4) Develop an Operational Procedure (Task Network Definition)

Select the standardised ITS User Services, Processes, Equipment Packages, and Functional Requirements
Integrated Service Planning (ISP)

1) Identify Needs and Scope
2) Determine Key Services and Functional Requirements
3) Define Terminators and Interfaces
4) Develop an Operational Procedure (Task Network Definition)

Defines the terminators interacting with the application and the interfaces Equipment Packages, communicating the messages among the consistent components of the ITSoS application
Integrated Service Planning (ISP)

1) Identify Needs and Scope
2) Determine Key Services and Functional Requirements
3) Define Terminators and Interfaces
4) Develop an Operational Procedure (Task Network Definition)

Use the Hierarchical Task Analysis (HTA) to define tasks, subtasks, sequence of execution, and conditions for triggering the actions.
Example: Abstract ITS plan of an ATIS Operation

Provide Traveller Information

- Provide Traveller with Personal Travel Information
- Collect ISP Services Data
  - Collect Traffic Data
  - Collect Emergency Traveller Data
  - Collect Transit Operations Data
  - Provide Dynamic Info
- provideDynamicInfo
- Provide Multimodal Route Selection
  - Provide Information To Travellers

a) Multimodal Mode Decomposition

b) Real-time Mode Decomposition (Auto Mode)

c) Real-time Mode Decomposition (Transit Mode)
Ontological Semantic Knowledge Representation (OSKR)
Selected segment of highway 401

Example

Sensing Service Y

Hwy401_Element 5951398

Roadway Basic Surveillance

Functional Requirement

Collect, process, digitize, and send traffic sensor data (speed, volume, and occupancy)

MTO

Sensing_Service_Y

shares

Loop_Detector_X

observes

Speed

hasSensor

implementsFunctionalRequirement

Starts

Roadway Basic Surveillance

OTN

OWL-S

SSN

Sensing_Service_Y_Profile

presents

Sensing_Service_Y_Pr

ofile

hasOutput

hasInput

startTime

trafficData

hasInput

endTime

hasOutput

MTO

3S

Example

Sensing Service Y

Hwy401_Element 5951398

Roadway Basic Surveillance

Functional Requirement

Collect, process, digitize, and send traffic sensor data (speed, volume, and occupancy)

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Sensing_Service_Y

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presents

Sensing_Service_Y_Pr

ofile

hasOutput

hasInput

startTime

trafficData

hasInput

endTime

hasOutput

MTO

3S
Proof-of-Concept ATIS Prototype

Open Street Maps

GTFS

TTC
GO
YRT
Brampton Transit
Oakville Transit
Durham Region
Transit
Burlington Transit
MiWay
Sensors
# Proof-of-Concept ATIS Prototype

<table>
<thead>
<tr>
<th>Service</th>
<th>ITS Abstract Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTAPlannerService</td>
<td>Provide Multimodal Route Selection</td>
</tr>
<tr>
<td>IncidentListInqRq</td>
<td>Collect Emergency Traveller Data</td>
</tr>
<tr>
<td>GTATrafficService</td>
<td>Collect Traffic Data</td>
</tr>
<tr>
<td>NextBusMessagesService</td>
<td>Collect Transit Operations Data</td>
</tr>
<tr>
<td>GTASTopsService</td>
<td>Collect Transit Operations Data</td>
</tr>
<tr>
<td>NextBusPredictionsService</td>
<td>Collect Transit Operations Data</td>
</tr>
</tbody>
</table>
Proof-of-Concept ATIS Prototype

Origin = 43.77010, -79.39596
Destination = 43.65968, -79.43184
Modes = CAR

Services:
GTATrafficService
IncidentListInqRq
Proof-of-Concept ATIS Prototype

Origin = 43.81967, -79.33022
Destination = 43.65943, -79.38789
Modes = WALK, TRANSIT

Services:
NextBusMessagesService (for route 53, 1)
GTAStopsService (for stops 10138, 14111)
NextBusPredictionsService (for stops 10138, 14111)
Proof-of-Concept ATIS Prototype

Origin = 43.80257, -79.39476
Destination = 43.68674, -79.39991
Mode = CAR_PARK, WALK, TRANSIT

Services:
- GTATrafficService
- IncidentListInqRq
- NextBusMessagesService (for route 1)
- GTAStopsService (for stops 14111)
- NextBusPredictionsService (for stops 14111)
An Example Request

```
{ "routeSegment": { 
  "routeSegmentMode": "CAR",
  "routeSegmentData": { 
    "routeSegmentStartPoint": "43.7701, -79.39596",
    "routeSegmentEndPoint": "43.65968, -79.43184",
    "routeSegmentEstimatedTravelTime": "1880",
    "routeDescription": { 
      "distance": "44.852000000000004",
      "streetName": "Elmwood Avenue",
      "absoluteDirection": "WEST",
      "relativeDirection": "DEPART",
      "longitude": "-79.39599121336225",
      "latitude": "43.77017845940073"
    },
    
    "distance": "572.227000000001",
    "streetName": "Wilfred Avenue",
    "absoluteDirection": "SOUTH",
    "relativeDirection": "LEFT",
    "longitude": "-79.39652810000001",
    "latitude": "43.77006710000006"
  }
  
  { 
    "distance": "553.8789999999999",
    "streetName": "Sheppard Avenue East",
    "absoluteDirection": "EAST",
    "relativeDirection": "LEFT",
  }
}
```
An Example Request (Cont.)

```json

```
```
Computational Performance Evaluation of the ITSoS Composer

**Initial Task**

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Plan Size</th>
<th>Normalized Response Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete traveller information services</td>
<td>4770</td>
<td>80.64</td>
</tr>
<tr>
<td>Pre-trip travel information</td>
<td>1711</td>
<td>53.89</td>
</tr>
<tr>
<td>En-route driver information</td>
<td>495</td>
<td>32.72</td>
</tr>
<tr>
<td>Route guidance and navigation</td>
<td>959</td>
<td>57.43</td>
</tr>
<tr>
<td>Ride matching and reservation</td>
<td>709</td>
<td>47.52</td>
</tr>
<tr>
<td>Travel-related services and facilities</td>
<td>1370</td>
<td>50.58</td>
</tr>
<tr>
<td>Trip planning service</td>
<td>537</td>
<td>38.21</td>
</tr>
<tr>
<td>Provide information on current situational information on transportation systems</td>
<td>519</td>
<td>45.17</td>
</tr>
<tr>
<td>Collect Traffic Data</td>
<td>9</td>
<td>4.58</td>
</tr>
<tr>
<td>Collect Highway Traffic information</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Effect of Increasing the number of discovery variables**

Response Time Normalized vs. Number of Variables

Response Time Normalized vs. Plan Size

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Transportation Research Institute
Conclusions

- The ITS standards provide a solution to the *syntactical* barriers of achieving interoperability within an ITSoS, however, they do not overcome the *semantic* interoperability barriers that hinder the ability of the ITSoS to *dynamically compose* its constituent components.
Conclusions

- The ITS standards provide a solution to the syntactical barriers of achieving interoperability within an ITSoS, however, they do not overcome the semantic interoperability barriers that hinder the ability of the ITSoS to dynamically compose its constituent components.

- There is a gap between the general processes, as represented by the ITS architecture, and the real processes developed by the transportation jurisdictions and municipalities. Such gap precludes the ability to use the architecture in the planning of ITSoS applications.
Conclusions

- Enabling an ITSoS requires:

  - A **common model** that formally represent involved cyber-physical components. The thesis suggests a *four-tier ontology* that acts as a common language describing ITSoS operations.

  - A **consistent method** by which stakeholders can use the reference model to define and adjust abstract ITSoS plans. The thesis suggests a *hierarchical task analysis* approach to formally describe these abstract plans.

  - An **execution engine** to compose and coordinate the constituent cyber-physical components of the ITSoS. The thesis suggest an *architecture* illustrating the main component of the engine.