Supplementary Technical Report

Full Details of 14 Case Studies in SmartUcon

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November 16, 2025

Abstract

This supplementary report provides complete details of the 14 case studies used to evaluate the applicability of SmartUcon across five domains: Smart Vehicles, Smart Cities, Smart Homes, Healthcare, and Industrial Environments. Each case study includes the modeling process, policy description, and evaluation results. Approximately 95% of the expected ALFA code was automatically generated, demonstrating the effectiveness of the DSML and EGL transformation.

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Chapter 1

Applicability Evaluation

1.1 Overview

One of the primary criteria for evaluating a DSML is its applicability in diverse and realistic scenarios. Applicability refers to the language's ability to accurately and precisely model the requirements of the target domain. In this research, to evaluate the applicability of SmartUcon, a set of 14 case studies in various domains—including smart vehicles, smart cities, smart homes, healthcare, and industrial environments—were designed and implemented.

Each case study followed a three-stage modeling process:

- Graphical modeling using the designed editor based on the UCON+ metamodel.
- Automatic transformation of the model into ALFA code using the developed EGL template.
- Evaluation of model complexity by counting the number of classes, attributes, and relationships used.

The following sections describe representative case studies from each domain.

1.2 Smart Vehicles

Smart vehicles represent a critical domain for dynamic and context-aware policies, particularly in safety, navigation, and traffic optimization.

1.2.1 Case 1: Car Speed Adaptation

This policy adjusts vehicle speed to enhance safety under varying conditions, using three authorization rules based on specific contexts. The first rule reduces speed to 60 km/h for wet, icy, or damaged roads, notifying the driver and commanding the vehicle's actuator. The second rule lowers speed to 50 km/h in high or moderate traffic, alerting the driver and issuing an actuator command. The third rule mandates a 55 km/h speed in rain, snow, or fog, with driver notification and actuator adjustment.

1.2.2 Case 2: Car Route Optimization

This policy optimizes vehicle routing in a smart navigation system, selecting suitable paths based on traffic, roadblocks, or low fuel levels, using three authorization rules. The first rule reroutes to a less congested path when high traffic density is detected by the trafficDensitySensor or excessive congestion occurs, notifying the driver via alert. The second rule proposes an alternative route if the current path is blocked or delayed, informing the driver of the change through a warning message. The third rule selects a fuel-efficient route when fuel levels fall below a set threshold, alerting the driver and adjusting the path to minimize consumption.

1.2.3 Case 3: Car Lane Change

This policy manages intelligent lane changes to enhance safety and optimize traffic flow, using three authorization rules based on specific conditions. The first rule (Deny) cancels lane change requests if the proximity sensor detects objects within 2 meters, notifying the driver. The second rule (Permit) allows lane changes to less congested paths during high traffic density and speeds below 30 km/h, informing the driver via alert. The third rule (Permit) permits lane changes in adverse weather (rain, snow, or fog) with visibility over 50 meters to improve road safety, issuing a notification.

1.3 Smart Cities

Urban environments require large-scale, real-time policies for safety and efficiency.

1.3.1 Case 4: City Emergency Situation

This policy manages urban emergencies, such as accidents or fires, by enabling rapid detection and real-time notification of response teams. It defines a single Permit authorization rule activated under specific conditions. The rule triggers when surveillance cameras detect an accident or fire in the context of emergency management, issuing a Permit decision. This activates an obligation to send a “notify police" command to the central system, alerting authorities immediately.

1.3.2 Case 5: City Light Management

This policy optimizes urban street lighting to enhance pedestrian safety in low-light conditions and improve energy efficiency. It employs two authorization rules based on environmental conditions. The first rule activates streetlights when ambient light falls below a threshold, a pedestrian is present, and the time is after 18:00. The second rule denies full lighting if energy consumption exceeds a set limit and the time is outside 12:00–14:00.

1.3.3 Case 6: City Traffic Management

This policy optimizes urban traffic light systems to improve traffic flow and reduce congestion, using two authorization rules based on traffic conditions and time. The first rule (Permit) activates during high traffic density between 7:00–13:00 or 17:00–22:00, adjusting traffic light timing to an optimal state. The second rule (Permit) eliminates additional traffic light timing when traffic density is very low and outside peak hours (22:00–7:00 or 13:00–17:00).

1.4 Smart Homes

Smart homes demand integrated policies across energy, security, and entertainment.

1.4.1 Case 7: Home Resource Control

This policy manages resources, social interactions, and network security in a smart home, using four authorization rules across various contexts. The first rule activates when over four people are present and a “guest arrival" event is detected, triggering obligations like preparing the room, activating the audio system, and brewing coffee. The second rule enables the gaming system if children are in the room after 18:00, ensuring appropriate entertainment. The third rule shuts off the water valve if consumption exceeds 100 liters after 20:00, optimizing water usage. The fourth rule (Deny) disconnects low-priority devices when the number of connected devices exceeds the limit and network security is reported as “low."

1.4.2 Case 8: Home Management

This policy enhances smart home security and energy efficiency through three Permit authorization rules activated by specific conditions. The first rule triggers when the door sensor detects an "open" status, activating the security alarm and notifying the homeowner. The second rule activates when the air sensor detects a temperature above 25°C, adjusting the HVAC system to 22°C and issuing a temperature adjustment notification. The third rule turns off house lights automatically after 20:00, using the Time Changing event to optimize energy use and sending a confirmation alert.

1.4.3 Case 9: Environmental Control

This policy optimizes waste management, air quality, and garden irrigation in a smart home through three Permit authorization rules activated by specific conditions. The first rule triggers when the trash bin sensor exceeds 90% capacity before 18:00, activating the cleaning robot. The second rule activates when the CO_2 sensor detects levels above 1000 units and windows are closed, turning on ventilation, opening windows, and sending an air quality alert. The third rule starts garden irrigation when soil moisture falls below 30% and weather is not rainy, snowy, or foggy.

1.5 Healthcare Environments

Healthcare scenarios require strict access, monitoring, and safety enforcement.

1.5.1 Case 10: Hospital Nurse Management

This policy optimizes emergency ward staffing by detecting critical patient surges and activating response protocols. It uses a single Permit authorization rule. The rule activates when patient numbers exceed 30 and fewer than 5 nurses are present, in the context of “staff management" and the “patient surge" event, using patient counting system data. It issues a Permit decision, notifying the nursing manager and sends an alert.

1.5.2 Case 11: Hospital Patient Monitoring

This policy enables real-time monitoring of patients’ vital signs, detecting critical conditions like elevated heart rates and alerting nurses. It uses a single Permit authorization rule. The rule activates when a patient’s heart rate exceeds 120 beats per minute and the patient is over 20 years old, in the “patient status control" context with a “heart rate increase" event, using heart rate sensor data. It issues an immediate alert to nurses, adjusts the IV drip via the ecgMonitor.

1.5.3 Case 12: Hospital Room Entrance

This policy ensures secure access control to sensitive hospital areas, preventing unauthorized entry. It employs a single Deny authorization rule. The rule activates when the subjectId, subjectName, subjectAuthentication, or room access is detected as “unknown" or “invalid," prohibiting entry. It uses the Unauthorized entry event, triggers an alert to the security team.

1.6 Industrial Environments

Industrial systems require policies for operator authorization and machine safety.

1.6.1 Case 13: Factory Machine Operators

This policy controls access to industrial machinery, ensuring only authorized, trained, and authenticated operators gain access. It includes two authorization rules. The first rule (Permit) grants access if the user's role is "operator," training is completed, authentication is successful, and access time is between 08:00–16:00, logging the access. The second rule (Deny) rejects access if security conditions are not met.

1.6.2 Case 14: Factory Production Machine Safety

This policy ensures the safety of production machinery by preventing accidents due to high temperatures or operational errors. It includes two Deny authorization rules. The first rule activates when the cutting machine's sensor detects a temperature above 80°C and the machine is "active," denying access, notifying technicians, shutting down the machine. The second rule triggers when the cutting machine encounters an error, denying access, informing technicians, and shutting down the machine.

1.7 Conclusion

Overall, the 14 case studies confirm that SmartUcon can effectively model a wide range of policies across domains. In all cases, approximately 95% of the expected ALFA code was automatically generated, requiring only minor manual adjustments. This demonstrates both the expressiveness of the language and the practicality of the transformation process.