

SWARCO Smart-AI

Technical Questions & Answers (Q&A) Client Technical Response

Author: Morten Søndergaard

Version: 1.0

Date: 16 July 2026

Introduction

The following Technical Questions & Answers (Q&A) document has been prepared in response to the technical questions received from our client's regarding the SWARCO Smart-AI solution.

The purpose of this document is to provide a clear overview of the Smart-AI system architecture, operation, learning process, safety mechanisms, cybersecurity, integration and operational principles. The information reflects the current capabilities of the SWARCO Smart-AI solution integrated into the ITC-3 traffic signal controller and is intended to support the technical evaluation of the system.

As Smart-AI is a rapidly evolving technology and the number of deployments continues to grow, new features, operational experience and best practices are continuously incorporated into the solution. Consequently, this document will be updated regularly to reflect the latest product capabilities and field experience.

Where appropriate, additional project-specific information can be provided during the detailed design and implementation phases.

Contents

Introduction	1
Contents	1
1. AI Controller Operation	3
1.1 How does the AI controller work during normal operation?	3
1.2 How does the controller receive data from the detection system?	3
1.3 How does Smart-AI analyse traffic movement and make decisions?	4
1.4 How does the controller apply the optimized signal timing?	5
2. AI Learning Process	5
2.1 How does Smart-AI learn from traffic data?	5
2.2 What types of data are collected and analysed?	5
2.3 How long does the learning and tuning period take?	6
2.4 How many AI models are used in Smart-AI?	7
2.5 How does the system improve the traffic plan over time?	7
2.6 Is learning automatic, or does it require engineer approval?	8
3. Safety and Fail-Safe Operation	8

3.1 What happens if Smart-AI provides incorrect data or abnormal recommendations?.....	8
3.2 How is abnormal AI behaviour detected?	8
3.3 How does the controller take over if Smart-AI fails?	9
3.4 What safe operating modes are available?	9
3.5 Can Smart-AI be programmed to comply with the national traffic regulations in my area?	10
3.6 Confirmation that the traffic signal controller remains in control	10
3.7 Confirmation of fallback operation	10
4. Manual Override and Engineer Control	11
4.1 How can an operator or engineer disable Smart-AI?.....	11
4.2 How can the system be switched to normal controller operation?	11
4.3 Do AI recommendations require approval before activation?	11
4.4 How are AI decisions and changes logged?	11
5. Cybersecurity and System Protection	12
5.1 How is communication between Smart-AI and the controller secured?	12
5.2 How is the system protected against unauthorised access?	12
5.3 What user access levels are available?	12
5.4 Are system logs and an audit trail available?.....	13
6. Integration and Architecture.....	13
6.1 Typical system architecture	13
6.2 Data-flow diagram.....	14
6.3 Server, VM and network requirements	14
6.4 Is continuous internet access required?.....	15
7. Required Manuals and Supporting Documents.....	15
8. Key Safety Statement	15

1. AI Controller Operation

1.1 How does the AI controller work during normal operation?

Smart-AI operates as an optimization layer connected to the traffic signal controller. The traffic signal controller continues to execute the approved signal program and remains responsible for all safety-critical functions.

During normal Smart-AI operation:

- The detection system measures traffic demand and movement.
- The traffic data is transferred to the Smart-AI engine.
- Smart-AI evaluates the current traffic situation and predicts the effect of different signal-control decisions.
- Smart-AI sends optimized control requests to the traffic signal controller.
- The controller validates and executes these requests within the approved signal program, safety rules and configured operating limits.

The controller can continue to operate in conventional vehicle-actuated (VA) mode whenever Smart-AI is disabled or unavailable.

Smart-AI does not directly switch signal lamps and cannot override the controller's safety system.

1.2 How does the controller receive data from the detection system?

Detector data can be received either:

- Directly by the traffic signal controller.
- Through a roadside perception or detection unit.
- Through the Smart-AI platform using a IP-based communication protocol.

Depending on the project, the detection sources may include:

- Radar detectors.
- Video detection.
- Thermal cameras.
- LiDAR.
- AI-based perception systems.
- Public transport priority inputs.
- Pedestrian and cyclist detectors.
- External traffic data sources.

Smart-AI requires an advanced detection system capable of providing real-time object-level data. At a minimum, the detection system should provide the position (coordinates) and speed of detected objects. For optimal traffic optimization, the system should also provide object classification, such as car, bus, truck, bicycle, pedestrian, etc. This rich detection data enables Smart-AI to accurately predict traffic behaviour and make optimal real-time control decisions.

The exact data protocol is detector manufacturer-specific. The interface may use a standard traffic protocol or a documented SWARCO interface. All transferred data is time-stamped and associated with the relevant detector, lane, approach or traffic movement.

Smart-AI already supports a number of detector communication protocols and interfaces from leading detection manufacturers. Additional detector interfaces are continuously being implemented as part of the ongoing Smart-AI development program, ensuring compatibility with an expanding range of advanced detection technologies.

1.3 How does Smart-AI analyse traffic movement and make decisions?

Smart-AI continuously evaluates the observed traffic state, including traffic demand, queues, arrivals, occupancy and movement through the intersection.

The system considers:

- Current and predicted vehicle queues.
- Traffic arrival patterns.
- Waiting times.
- Traffic volumes.
- Lane utilisation.
- Turning movements.
- Pedestrian and cyclist demand.
- Public transport priority, where applicable.
- Coordination with neighbouring intersections. (Currently in development)
- Minimum and maximum green times.
- Intergreen and clearance requirements.
- Approved stage structures and signal groups.
- Configured operational priorities.

The AI evaluates possible control actions and selects the action expected to produce the best overall traffic result according to the configured objectives.

Typical objectives include:

- Reducing queue lengths.
- Reducing average delay.
- Reducing the number of stops.
- Improving travel-time reliability.
- Prioritising selected traffic movements.
- Supporting public transport priority.
- Preventing queue spillback.
- Improving corridor progression.

The AI can optimise traffic performance only within the control possibilities and safety constraints made available by the approved controller configuration.

1.4 How does the controller apply the optimized signal timing?

Smart-AI sends an authorized control request to the controller:

- Extending or terminating a permitted green phase.
- Extending or terminating a permitted signal group.
- Requesting an approved traffic stage.

Before execution, the controller checks whether the request is valid and permitted.

The controller continues to enforce:

- Conflict monitoring.
- Minimum green times.
- Maximum green times.
- Intergreen periods.
- Clearance times.
- Pedestrian safety times.
- Signal-group compatibility.
- Approved stage sequences.
- Local controller safety rules.

Any request that is invalid, outside the configured limits or incompatible with the approved signal program is rejected by the controller.

2. AI Learning Process

2.1 How does Smart-AI learn from traffic data?

Smart-AI uses **Reinforcement Learning (RL)** to continuously optimize traffic operation. Reinforcement Learning enables the AI to learn by interacting with the traffic environment and evaluating the outcome of each control decision.

The AI observes current traffic conditions, selects the most appropriate control action, and measures the resulting traffic performance. Based on this feedback, it continuously refines its decision-making strategy to improve overall traffic flow.

The learning process evaluates and compares:

- The traffic situation before an action.
- The selected signal-control action.
- The resulting queues, delays and traffic movements.
- The difference between predicted and actual traffic behaviour.

Through this continuous trial-and-feedback process, Smart-AI develops an increasingly accurate understanding of how an intersection or corridor responds to different traffic conditions, enabling it to make better optimization decisions over time.

Learning takes place within a defined operational environment. The AI cannot modify the controller's safety configuration, conflict matrix, intergreen values or any other safety-critical parameters. These remain under the full control of the traffic signal controller and the traffic engineer.

2.2 What types of data are collected and analysed?

Depending on the installed detection system, Smart-AI may process:

- Vehicle counts.
- Vehicle presence.
- Detector occupancy.
- Vehicle speed.
- Queue length.
- Lane utilisation.
- Turning movements.
- Arrival rates.
- Departure rates.
- Waiting time.
- Travel time.
- Number of stops.
- Signal status.
- Active stage or phase.
- Green, red and amber durations.
- Pedestrian and cyclist demand.
- Public transport priority requests.
- Emergency or special priority requests.
- Controller alarms and operational status.

Where LiDAR, radar or camera-based perception is used, the system can normally work with anonymous object data rather than storing identifiable images.

2.3 How long does the learning and tuning period take?

The required period depends on:

- Intersection complexity.
- Number and quality of detectors.
- Variation in traffic demand.
- Availability of representative peak-period data.
- Coordination with neighbouring intersections.
- The project's performance objectives.
- Whether the system is installed at one intersection or across a corridor.

A typical implementation includes:

- Data and detector validation.
- Baseline measurement under existing control.
- Initial Smart-AI configuration.
- Controlled activation.
- Performance monitoring and engineering review.
- Final tuning and acceptance.

Initial operation can normally begin immediately after system configuration and validation. The AI control algorithm continuously optimizes its performance based on observed traffic

conditions. The learning period depends on the complexity of the intersection and traffic patterns and typically ranges from a few minutes to several days.

2.4 How many AI models are used in Smart-AI?

Smart-AI uses multiple specialized AI models working together to optimize traffic operation in real time. Rather than relying on a single AI algorithm, the system combines several AI-assisted functions, each optimized for a specific traffic-engineering task.

The Smart-AI algorithm uses AI for:

- **Prediction of incoming traffic** – Predicts approaching traffic demand before vehicles reach the intersection.
- **Dynamic traffic cost calculation** – Continuously evaluates traffic conditions by assigning different costs to moving and stationary vehicles, enabling optimization of overall traffic flow.
- **Turning-movement prediction** – Predicts the percentage of vehicles turning left, right or continuing straight to improve signal-timing decisions.
- **Signal switch-point optimization** – Determines the optimal moment to change signal stages while balancing efficiency, delay and safety.
- **Lane-geometry modelling** – Uses the physical lane layout and permitted traffic movements to improve decision-making.
- **Platoon speed estimation** – *currently under development* – Calculates the speed and expected arrival time of vehicle platoons travelling towards downstream intersections to support coordinated traffic progression.

These AI models continuously exchange information and update their predictions every 100 ms, enabling Smart-AI to respond dynamically to changing traffic conditions while operating within the safety constraints of the SWARCO ITC-3 traffic signal controller.

2.5 How does the system improve the traffic plan over time?

Smart-AI continuously updates its understanding of:

- Traffic demand patterns.
- Queue development.
- Arrival profiles.
- Traffic response to different control actions.
- Recurring congestion.
- Changes between peak and off-peak operation.
- Seasonal or event-related traffic conditions.

Smart-AI continuously evaluates the traffic situation and makes optimization decisions every 100 ms. Each decision is based on the current traffic conditions and predicted traffic development, allowing the controller to respond dynamically to changing demand in real time.

Performance can be monitored against KPIs such as:

- Average delay.
- Maximum queue.
- Average queue.
- Number of stops.
- Throughput.
- Travel time.

- Public transport delay.
- Pedestrian waiting time.

2.6 Is learning automatic, or does it require engineer approval?

Smart-AI uses Reinforcement Learning (RL) to continuously optimize traffic operation. The learning process is fully automatic and does not require engineering approval during normal operation.

The AI continuously evaluates the effect of its control decisions and adjusts its optimization strategy based on measured traffic performance. Every decision is made within the operational boundaries and constraints configured in the traffic signal controller.

The AI cannot modify safety-critical controller parameters such as conflict matrices, intergreen times, minimum safety times, or approved stage and signal group structures. These parameters remain exclusively under the control of the traffic engineer and can only be changed using the standard ITC-3 engineering tools ITC-PC and its configuration process, including ITC-PCs established verification and approval procedures.

This approach combines fully automatic traffic optimization with the proven safety and reliability of the traffic signal controller.

3. Safety and Fail-Safe Operation

3.1 What happens if Smart-AI provides incorrect data or abnormal recommendations?

All Smart-AI requests are subject to validation by the traffic signal controller and the Smart-AI/ITC-3 interface.

Requests can be rejected if they are:

- Outside the permitted timing range.
- Inconsistent with the controller state.
- Received too late.
- Incorrectly formatted.
- Outside an approved operating period.
- In conflict with a higher-priority function.
- Incompatible with the signal program.
- Repeated at an abnormal frequency.
- Based on missing or invalid input data.
- Outside defined operational boundaries.

An incorrect AI recommendation cannot bypass the controller's safety logic.

3.2 How is abnormal AI behaviour detected?

Abnormal behaviour can be detected through several mechanisms:

- Communication timeout.
- Heartbeat monitoring.
- Missing or stale data detection.
- Message sequence validation.
- Range and plausibility checks.

- Detection of invalid commands.
- Monitoring of recommendation frequency.
- Controller-state validation.
- Detector quality monitoring.
- Performance threshold monitoring.
- Alarm generation.
- Watchdog functions.
- Comparison against configured operational limits.

If the Smart-AI connection is lost or its data becomes invalid, the controller automatically continues with its configured local control strategy.

3.3 How does the controller take over if Smart-AI fails?

The controller always remains operational independently of Smart-AI.

In case of AI failure, communication failure or invalid data, the controller will automatically fall back to one of the configured local operating modes, for example:

- Conventional vehicle-actuated control.
- Fixed-time operation.
- Time-of-day signal plans.
- Traffic-responsive plan selection.
- Local adaptive control.
- Pre-approved fallback signal plans.
- Manual operation.
- Flashing or dark mode where permitted and specifically configured for emergency use.

The selected fallback strategy is defined in ITC-PC during configuration of the ITC-3 controller.

3.4 What safe operating modes are available?

Available modes depend on the controller configuration but may include:

- Smart-AI enabled operation.
- Local vehicle-actuated operation.
- Fixed-time operation.
- Time-of-day plan operation.
- Pre-approved traffic plan selection.
- Manual engineer-selected plan.
- Central traffic-management control.
- Local controller fallback.
- Emergency or special operating mode.
- Flashing operation where legally permitted.
- Lamps-off operation where legally permitted.

The applicable safe operating modes must be selected in accordance with national traffic regulations and the client's operational requirements. Configuration is carried out in ITC-PC using the standard engineering procedures for the SWARCO ITC-3 traffic signal controller, ensuring that Smart-AI follows the same configuration, verification and approval process as a conventional ITC-3 installation.

3.5 Can Smart-AI be programmed to comply with the national traffic regulations in my area?

Yes.

Smart-AI is an optimization layer that operates on top of the standard SWARCO ITC-3 traffic signal controller. It does not replace or modify the controller's fundamental traffic control logic or safety functions. Instead, all optimization decisions are executed within the operational and safety constraints configured in the ITC-3 controller.

As a result, Smart-AI fully complies with the national traffic regulations, controller standards and approved signal control principles configured for each installation.

The SWARCO ITC-3 traffic signal controller is installed in more than 70 countries worldwide, each with its own traffic regulations, standards and operational requirements. Smart-AI has been designed to operate within these existing country-specific controller configurations, allowing it to be deployed without changing the underlying regulatory compliance of the traffic signal controller.

This architecture enables Smart-AI to optimize traffic flow while ensuring that all signal timings, stage sequences and safety-critical functions continue to comply with the applicable national and local traffic regulations.

3.6 Confirmation that the traffic signal controller remains in control

The traffic signal controller always remains responsible for the safe operation of the traffic signals.

Smart-AI:

- Cannot directly energise or switch signal lamps.
- Cannot disable conflict monitoring.
- Cannot change the controller's safety matrix.
- Cannot shorten mandatory safety periods below approved values.
- Cannot create an unapproved conflicting signal state.
- Cannot override the controller's safety-critical software.
- Cannot prevent the controller from entering its configured fallback mode.

The controller will not execute an AI request that violates the approved signal configuration or controller safety rules.

3.7 Confirmation of fallback operation

The controller can be configured to fall back automatically to:

- Fixed-time control.
- Vehicle-actuated control.
- Time-of-day plans.
- Pre-approved signal plans.
- Other approved local control strategies.

The exact fallback mode and transition conditions are defined in the site configuration and acceptance documentation.

4. Manual Override and Engineer Control

4.1 How can an operator or engineer disable Smart-AI?

Smart-AI can be enabled or disabled simply by changing the operating plan in the traffic signal controller. When a conventional signal plan is selected, the controller immediately resumes normal operation without Smart-AI. The change can be made locally or remotely through the standard controller or traffic management system interface, depending on the project configuration., depending on the project architecture:

- Controller engineering interface.
- Local controller operation panel.
- Smart-AI operator interface. (Web page)
- Central traffic management system.
- Configured digital input or operating command.
- Removal or disabling of the AI communication service.

The user must have the required access rights to perform the change.

4.2 How can the system be switched to normal controller operation?

The operator can select a configured conventional operating mode, such as:

- Vehicle-actuated operation.
- Fixed-time operation.
- Time-of-day plan operation.
- A specific pre-approved signal plan.
- Central system operation.

When Smart-AI is disabled, the controller continues operating without dependency on the AI algorithm.

The transition will take place at a safe point in the signal sequence to avoid unnecessary interruption to traffic operation.

4.3 Do AI recommendations require approval before activation?

This is configurable.

During commissioning, the system will normally begin in normal VA mode. Automatic activation should take place only after:

- Detection data has been validated.
- Communication has been tested.
- Fallback operation has been verified.
- Operational limits have been approved.
- The client and responsible traffic engineer have accepted the configuration.

After approval, Smart-AI can operate automatically within the agreed operational boundaries.

4.4 How are AI decisions and changes logged?

Smart-AI provides dedicated web-based dashboards that allow operators and traffic engineers to monitor the complete operation of the system in real time as well as review historical performance.

- Real-time intersection status.
- Live traffic flows and queue lengths.
- Current controller state and signal stage.
- AI decisions and optimization actions.
- Traffic performance indicators (KPIs).
- Historical traffic and performance trends.
- Detector and sensor status.
- Communication status.
- System alarms and warnings.
- Manual operator actions and mode changes.
- System event and diagnostic logs.

The web interface enables operators to verify that Smart-AI is operating as intended and provides valuable tools for performance analysis, troubleshooting, and continuous optimization. Historical data can be retained and exported in accordance with the client's operational and reporting requirements.

5. Cybersecurity and System Protection

5.1 How is communication between Smart-AI and the controller secured?

The Smart-AI algorithm runs on the dedicated second CPU inside the SWARCO ITC-3 traffic signal controller. Communication between the Smart-AI processor and the traffic signal controller takes place internally via the controller's backplane and does not rely on any external network connection.

This embedded architecture significantly reduces the cybersecurity attack surface by eliminating external communication for real-time AI operation. External network connections are only required for optional engineering access, remote diagnostics or software updates and can be secured using the standard cybersecurity features of the ITC-3 controller and the client's network infrastructure.

5.2 How is the system protected against unauthorised access?

Smart-AI is fully integrated into the SWARCO ITC-3 traffic signal controller and therefore uses the same cybersecurity architecture and access protection mechanisms as the standard ITC-3 controller.

Access to Smart-AI is controlled through the ITC-3 user authentication and authorization system, ensuring that only authorized users can configure or operate the system. All security features, including user management, password protection, remote access, software updates and system logging, are identical to those used for standard ITC-3 operation.

5.3 What user access levels are available?

ITC-3 controllers operating Smart-AI use the standard user access levels of the traffic signal controller. The available access levels are identical to those used for normal controller operation, ensuring consistent user management and security.

5.4 Are system logs and an audit trail available?

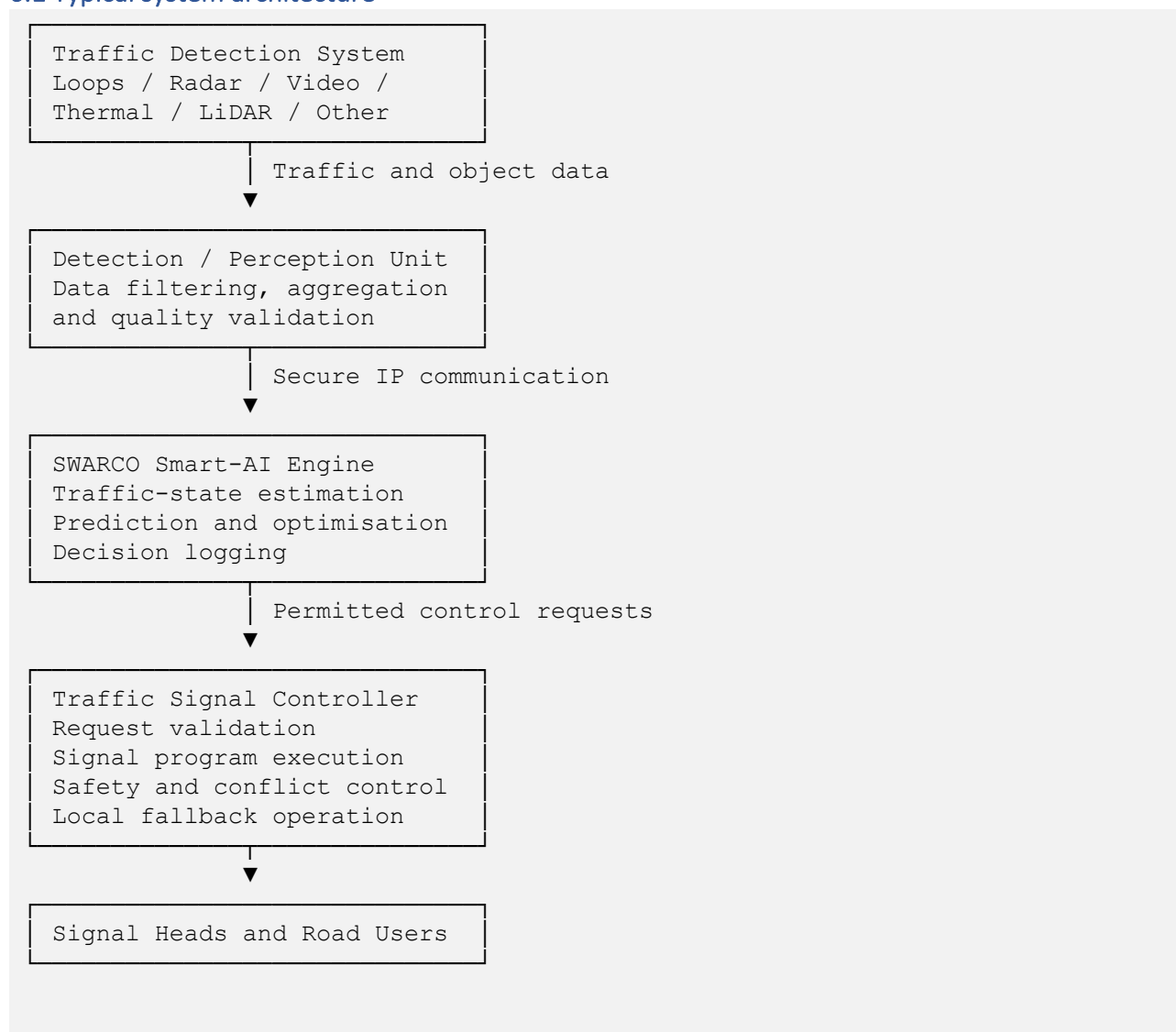
Smart-AI is fully integrated into the SWARCO ITC-3 traffic signal controller and therefore uses the same logging and audit trail facilities as the standard ITC-3 controller.

All operational events, user actions, configuration changes, alarms and system events are logged through the ITC-3 logging system. In addition, Smart-AI provides dedicated operational logs and performance data through its web-based monitoring interface, enabling traffic engineers to review AI operation, optimization decisions and system performance.

Log retention, export and backup are handled in the same way as for a standard SWARCO ITC-3 traffic signal controller, using the standard engineering tools and procedures.

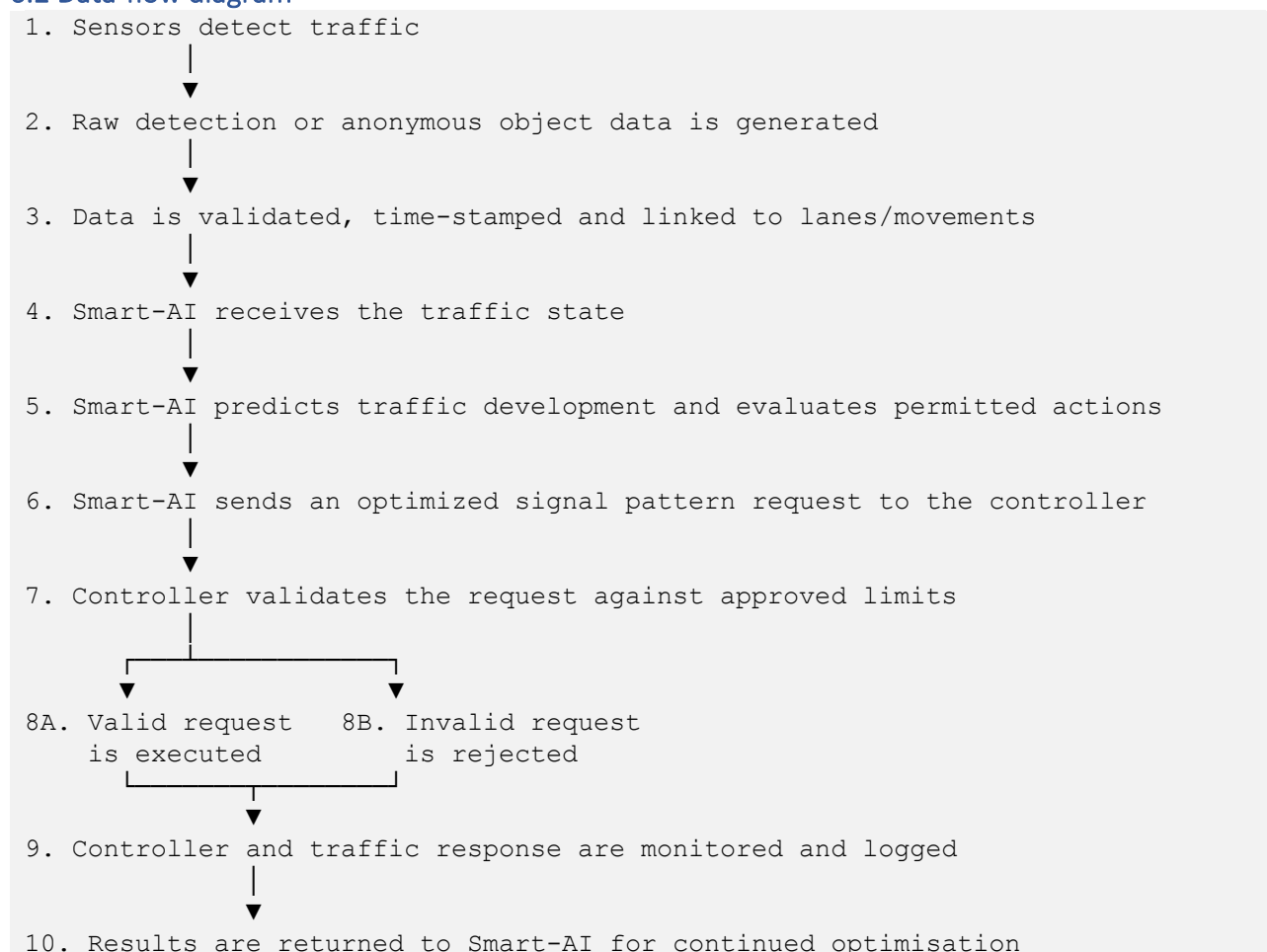
6. Integration and Architecture

6.1 Typical system architecture



The Smart-AI engine runs on the dedicated second CPU within the SWARCO ITC-3 traffic signal controller. This architecture eliminates the need for an external AI server, virtual machine or cloud connection for real-time operation. By executing directly inside the controller, Smart-AI benefits from low latency, high reliability and deterministic performance while maintaining full integration with the controller's safety and operational functions.

6.2 Data-flow diagram



6.3 Server, VM and network requirements

No dedicated server, virtual machine or external computing platform is required for Smart-AI operation.

The Smart-AI algorithm runs directly on the dedicated second CPU inside the SWARCO ITC-3 traffic signal controller. All real-time AI processing is therefore performed locally within the controller, eliminating the need for external processing hardware or cloud-based computing.

The only external requirements are the traffic detection system, such as LiDAR, radar or other approved detectors, and the communication interfaces required to exchange detector data with the controller.

This embedded architecture provides:

- No external AI server or VM.
- Low-latency real-time operation.
- High system reliability and availability.
- Reduced network dependency.
- Simplified installation and maintenance.
- No internet connection required for normal AI operation.

6.4 Is continuous internet access required?

No!

Smart-AI does not require continuous internet access for normal operation.

The system is designed to operate autonomously within the ITC-3 traffic signal controller, with all real-time AI processing performed locally on the controller's dedicated second CPU. This ensures reliable operation independent of cloud services or external network connectivity.

Internet access may be used for remote diagnostics, software updates or engineering support, but it is not required for normal traffic operation.

Loss of internet connectivity does not affect Smart-AI operation or the safe operation of the traffic signal controller. The controller continues operating normally using the embedded Smart-AI algorithm or, if required, its configured local fallback mode.

7. Required Manuals and Supporting Documents

As Smart-AI is fully integrated into the SWARCO ITC-3 traffic signal controller, the standard **ITC-3** and **ITC-PC** manuals are applicable for Smart-AI operation.

In addition, Smart-AI is a new technology, and SWARCO Technology is currently developing dedicated Smart-AI documentation. These manuals will provide detailed guidance on system operation, commissioning, optimization, performance monitoring, and best practices for deployment and maintenance. The documentation will be continuously updated as new features are introduced and operational experience is gained.

8. Key Safety Statement

SWARCO Smart-AI is an optimisation system and not a replacement for the safety functions of the traffic signal controller.

The traffic signal controller remains in full control of the signal installation at all times. It executes only valid and permitted requests, maintains all approved safety timings and prevents conflicting or unsafe signal states.

If Smart-AI, the detection system, the communication network or the associated Traffic Management System becomes unavailable, the traffic signal controller continues operating using its configured local fallback strategy, such as vehicle-actuated control, fixed-time control or a pre-approved signal plan.