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Conceptual Design of an ESP32-Ultrasonic-Based Patient Visitor Counting System for Health Information Education

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ABSTRACT

This study presents a conceptual design of an ESP32-based patient visitor counting system for healthcare registration units and its potential use as a practical learning medium for Medical Records and Health Information (RMIK) students. The Rational Unified Process (RUP) was used to structure the design into inception, elaboration, construction, and transition activities. The resulting conceptual outputs comprise a registration-area layout, system architecture, flowchart, wiring diagram, and 16×2 LCD display design. The proposed architecture uses an ESP32 microcontroller, two HC-SR04 ultrasonic sensors for sequential detection of inbound and outbound movement, a 16×2 I2C LCD for local display, and a buzzer for event feedback, with Wi-Fi connectivity reserved for future IoT-based monitoring. The study does not report experimental prototype performance; therefore, detection accuracy, counting error, response latency, detection distance, and inbound/outbound classification accuracy remain to be validated through physical implementation and repeated trials. The contribution is primarily an application-oriented conceptual architecture connecting automated visitor-flow monitoring in healthcare registration with technology-supported RMIK education.

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1. INTRODUCTION

Recording patient visits is an important activity in healthcare registration because visit-flow information can support workload assessment, staffing decisions, and service-quality evaluation. In practice, registration units may still rely on manual observation or registration records that do not provide an immediate count of people physically present in the service area. Evidence from healthcare queue studies indicates that the relationship between patient arrival and service capacity can affect waiting and congestion [1], [2] A lightweight visitor-flow counter can therefore be considered as a complementary monitoring device rather than a replacement for the official patient registration or health information system.

Automatic people-counting technologies generally use contact mechanisms, infrared/proximity sensors, ultrasonic sensing, or camera-based computer vision. Non-contact sensors are attractive for registration environments because they can detect movement without requiring patients to interact with the device. Ultrasonic sensing estimates object presence from reflected sound waves, while camera-based approaches can provide richer object information but may introduce additional computational, privacy, and lighting considerations. Recent work using ESP32 and ultrasonic sensing has demonstrated the feasibility of low-cost IoT counting in non-healthcare settings [3], while camera-based ESP32 systems have also been applied to people counting in smart buildings [4].

The development of ESP32-based IoT systems further expands the potential for local counting devices to transmit monitoring data. Setiawan et al. developed an ESP32-ultrasonic consumer-counting system with LCD and Blynk connectivity and reported a 1% counting error after prototype testing [3]. Putra et al. developed an IoT-based closed-room people counter using ESP32-CAM and infrared proximity sensing, with counts displayed locally and through a web/database environment [4]. Used ESP32-CAM and YOLOv3 for smart-building people detection and reported mean average precision above 90% across several lighting conditions [4]. In healthcare, Sandy et al. proposed an ESP32-based IoT queue-calling system for primary-care facilities, showing the relevance of embedded IoT technology to patient-flow management [5]. These studies demonstrate technological feasibility, but sensing technology, deployment environment, and validation procedures differ substantially across applications.

1.1 State of the Art and Comparative Positioning

Visitor-counting research can be differentiated along six dimensions relevant to the present study: microcontroller or computing platform, sensing technology, bidirectional or directional movement detection, IoT connectivity, deployment environment, and performance evaluation. The comparison below indicates that the proposed study does not claim technological novelty in ultrasonic counting itself. Instead, its contribution is the contextual integration of a low-cost ESP32-ultrasonic architecture with healthcare registration monitoring and RMIK learning. This distinction is important because the present manuscript reports a conceptual design rather than experimentally validated engineering performance.

Table 1. Comparison of Previous Studies and the Proposed ESP32-Based Visitor Counting System

Study	Platform	Sensing / detection	Direction / counting	Deployment	Validation / result	Position
Setiawan et al. (2024) [3]	ESP32	Ultrasonic	Consumer counting	Store	Prototype tested; 1% error	Technologically close; non-healthcare
Putra et al. (2022) [6]	ESP32-CAM	Infrared proximity	Entry/exit and occupancy	Closed room	LCD/web/database implementation	IoT occupancy; different sensor
Yoga et al. (2023) [4]	ESP32-CAM	Camera + YOLOv3	People detection/counting	Smart building	mAP >90% under five lighting conditions	Higher-complexity vision; non-healthcare
Sandy et al. (2025) [5]	ESP32	IoT queue architecture	Patient queue calling	Primary care	Healthcare IoT system proposed	Closest healthcare context; different function
Ghaffari et al. (2021) [7]	Web simulator	HIS simulation	Admission/discharge/transfer	HIT education	Skills improved in 6/8 processes	Educational rationale; no physical sensing
Choi et al. (2021) [8]	Simulated EHR	EHR simulation	Informatics learning	Health education	Simulation used to assess informatics competency	Educational rationale; different technical object

1.2 Study Objective and Contribution

Accordingly, this study aims to design a conceptual ESP32-HC-SR04 visitor-counting architecture tailored to the registration area of a healthcare facility and to articulate how the architecture can be used as a practical learning medium for RMIK students at Baubau Polytechnic. The contribution is application-oriented rather than a claim of new ultrasonic sensing technology. The proposed design specifies sensor placement, movement-sequence logic, local display, event feedback, and an extensible Wi-Fi/IoT interface. Because no physical prototype was constructed and tested, all engineering performance measures remain proposed evaluation targets for subsequent work

Although automatic counting has been demonstrated in several environments, the literature reviewed above does not establish a validated ESP32-ultrasonic visitor counter specifically configured for healthcare registration and simultaneously framed as an RMIK learning artifact. The gap is therefore contextual and educational rather than a claim that the underlying ultrasonic counting technology is new.

Based on this gap, the study focuses on a conceptual design of an ESP32-based patient visitor counter for healthcare registration areas and on its potential role as a practical learning medium for RMIK students at Baubau Polytechnic. The proposed architecture supports learning about sensor-based event detection, embedded-system logic, patient-flow monitoring, and the relationship between operational data and health information systems. The design is a pre-implementation specification; empirical accuracy and reliability are outside the scope of the present study.

2. RESEARCH METHOD

2.1. Types of research

This study is a systems-engineering conceptual design study using the Rational Unified Process (RUP) as the development framework [9]. RUP provides an iterative structure for requirements identification, architectural elaboration, construction of design artifacts, and transition documentation. The study stops at the conceptual-design stage and does not include physical prototype construction, laboratory performance testing, or user-effectiveness testing. Consequently, the outputs are design specifications rather than experimentally validated system performance.

2.2. Data collection technique

Data collection for requirements analysis consisted of literature review, observation, interviews, and documentation [10-11]. The literature review examined scientific publications, textbooks, and component technical documents. Observation focused on the registration-area layout, patient movement patterns, and the flow between entrance, waiting, and service points. Interviews with registration personnel, managers, lecturers, and students were used to identify functional and educational requirements [18]. These activities defined design requirements only; they were not an empirical test of counting accuracy or system reliability.

2.3. Research Stages

2.3.1 Inception Phase

This phase aims to understand the scope and objectives of the system. Activities include problem identification, functional and non-functional requirements analysis, definition of research objectives, and literature review [12]. Functional requirements include: (1) detecting incoming and outgoing patients using ultrasonic sensors, (2) distinguishing the direction of movement based on the detection sequence of the two sensors, (3) recording the number of incoming, outgoing, and waiting patients, (4) displaying data on a 16×2 LCD, (5) providing audio feedback via audible signals, and (6) sending data to an IoT platform [13]. Non-functional requirements include the use of readily available components, good detection accuracy, fast response time, and the potential for an effective learning environment [14,7].

2.3.2 Elaboration Phase

This stage is the system design stage, which includes system architecture design, component selection, and design model creation [9,15]. The system architecture consists of input (two HC-SR04 ultrasonic sensors), processing (ESP32 as the central processing unit), output (16×2 LCD and signal), and power supply [16,17].

The selected components include:

Table 2. Hardware Components Used in the Proposed System

No.	Component	Specification	Function
1	ESP32 DevKit V1	Dual-core Xtensa LX6, 240 MHz, 520 KB SRAM, 4 MB Flash, Wi-Fi/Bluetooth	Main controller of the system
2	HC-SR04 Ultrasonic Sensor	5 V, 40 kHz, detection range 2–400 cm	Detects patient movement
3	16×2 I2C LCD	16 characters × 2 lines, 5 V	Displays the patient visit count
4	Buzzer	5 V active buzzer	Provides an audible detection indicator
5	Power Supply	5 V DC, 2 A	Supplies electrical power to the system

The sensor configuration is determined by placing two ultrasonic sensors in pairs. The first sensor is placed outside (incoming direction) and the second sensor is placed inside (outgoing direction) to distinguish the direction of movement based on the detector sequence [17, 18].

2.3.3 Construction Phase

Because this research is limited to conceptual design without physical implementation, the Construction phase focuses on producing detailed design artifacts rather than a tested prototype. The outputs include a registration-area layout, block diagram, flowchart, schematic/wiring diagram, and LCD display design. No numerical claims about detection accuracy, counting error, response latency, detection distance, or classification accuracy are made in this phase.

2.3.4 Transition Phase

This phase is the stage of compiling complete and structured system design documentation, as well as recommendations for further development [9].

2.4 Research Workflow

The research workflow is structured as follows: problem identification → literature study and observation → needs analysis → Inception phase → Elaboration phase (architectural design, component selection) → Construction phase (block diagram creation, flowchart, schematic/wiring diagram, LCD design) → Transition phase (documentation and recommendations) → research report [9, 15].

3. RESULTS AND DISCUSSION

3.1 Requirements Analysis

The requirements derived from observation, interviews, and literature were divided into functional and non-functional requirements. Functional requirements are: (1) detecting movement through two ultrasonic sensors, (2) inferring movement direction from the order in which the sensors are triggered, (3) maintaining conceptual counts of inbound, outbound, and current occupancy, (4) displaying counts on a 16×2 LCD, (5) providing an audible event indication, and (6) providing an interface for future IoT transmission. Non-functional requirements are the use of readily available components, non-contact sensing, understandable response logic, maintainability, and suitability for practical RMIK learning. These requirements describe intended functionality and should not be interpreted as validated performance measures.

3.2 System Design Layout

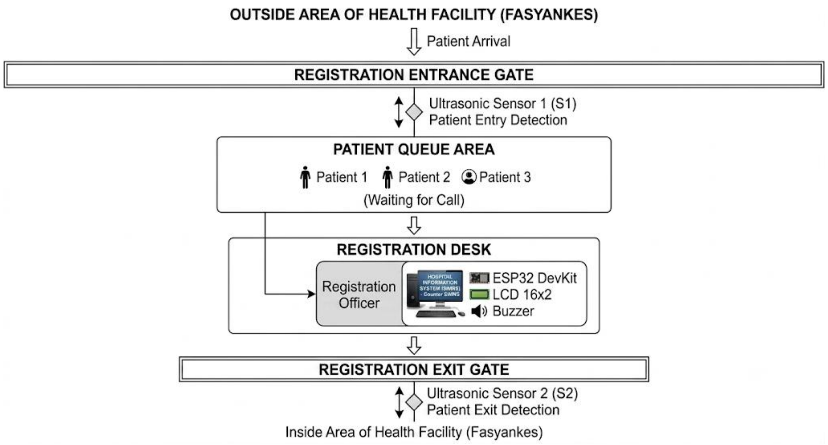

Figure 1. Layout of the ESP32-Ultrasonic Based Patient Visitor Counter Design
Source: Authors' design based on registration-flow requirements and prior visitor-counting architectures [24], [27].

Figure 1 shows the design of an ESP32-based patient visitor counter in the registration area of a healthcare facility. This system consists of several key components strategically placed in the registration area. Ultrasonic sensor 1 (S1) is placed outside the registration area entrance to detect incoming patients, and ultrasonic sensor 2 (S2) is placed inside the registration area exit to detect outgoing patients [17]. The dual placement of the two sensors allows the system to differentiate movement directions based on the order of detection. If S1 detects an object first, followed by S2, the system registers it as an incoming movement. Conversely, if S2 detects it first, followed by S1, the system registers it as an outgoing movement [14, 18].

The patient queue area is located between the entrance and the registration counter, where patients wait their turn to be served. The registration counter is where staff serve patients and input data into the hospital information system. A control system containing an ESP32, a 16x2 LCD, and a buzzer is placed near the registration counter for easy monitoring by staff [16, 19]. A 5V DC power supply supplies power to all system components.

3.3 System Block Diagram

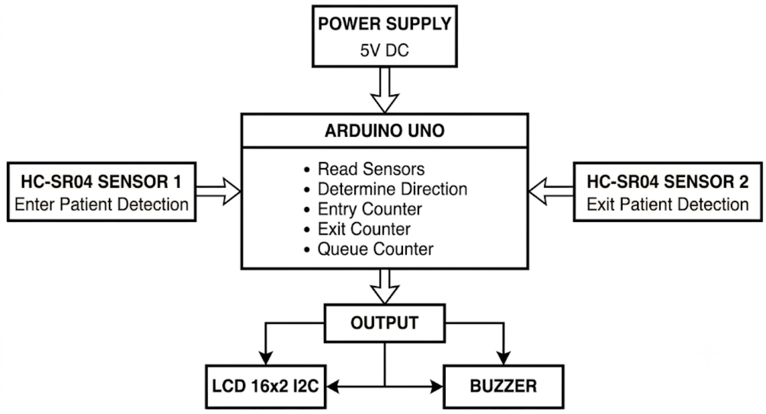

Figure 2. Block Diagram of ESP32-Ultrasonic Based Patient Visitor Counter
Source: Authors' design based on the proposed system architecture and component specifications [16, 3].

Figure 2 shows a block diagram of an ESP32-based patient visitor counter. This system consists of three main components: input, process, and output. In the input section, two HC-SR04 ultrasonic sensors function as patient movement detectors [14, 17]The ultrasonic sensors transmit 40 kHz ultrasonic signals and receive the reflections to detect the presence of objects at a distance of 2-400 cm [17]. The signals from the sensors are sent to the ESP32 as a central processing unit [3].

At the processing stage, the ESP32 is designed to interpret the temporal sequence of the two ultrasonic sensors. A sequence in which S1 is triggered before S2 is interpreted as an inbound event, whereas S2 followed by S1 is interpreted as an outbound event. The controller would then update the corresponding counters and calculate current occupancy as inbound events minus outbound events. The ESP32's integrated Wi-Fi provides an extensible communication layer for future IoT transmission [16, 3]. Because the present study does not implement the prototype, this logic represents the intended algorithm rather than a validated classification result.

In the output section, the 16×2 LCD displays information on the number of patients entering, leaving and queuing in real-time [20, 21]. The buzzer provides a sound indicator whenever patient movement is detected. The system can also send visit data to the IoT platform via a Wi-Fi connection [16].

3.4 System Flowchart

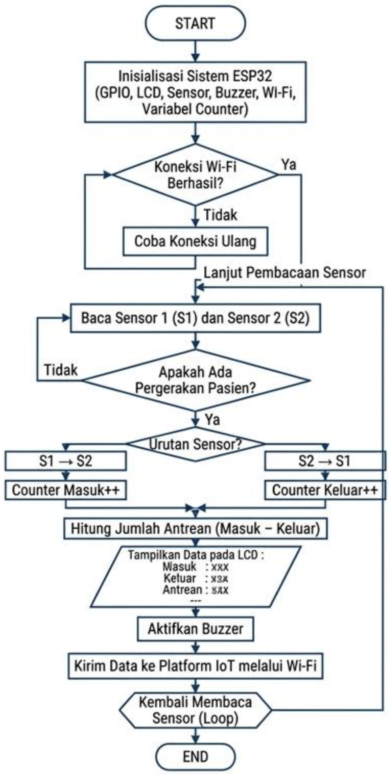

Figure 3. Flowchart of ESP32-Ultrasonic Based Patient Visitor Counter
Source: Authors' design based on bidirectional sensor-sequence logic [3], [6].

Figure 3 specifies the intended program logic. The process begins with initialization of the ESP32, sensors, display, buzzer, and future Wi-Fi connection. The controller then reads both sensors and evaluates their activation sequence. S1 followed by S2 is classified as an intended inbound event, while S2 followed by S1 is classified as an intended outbound event. The conceptual occupancy value is calculated as total inbound events minus total outbound events and is displayed on the LCD. Event data can subsequently be transmitted to an IoT platform through Wi-Fi. This flowchart describes proposed control logic; it does not constitute evidence that the sequence classifier achieves a particular accuracy in practice.

If Sensor 1 (S1) detects an object first and then Sensor 2 (S2), the system records it as an inbound movement and increments the inbound patient counter. If Sensor 2 detects an object first and then Sensor 1, the system records it as an outbound movement and increments the outbound patient counter [6, 18]. After the counter value is updated, the system counts the number of patients in the queue (total inbound minus total outbound) and displays the data on a 16×2 LCD [20, 19]. When any movement is detected, an alarm is triggered, such as an audible indicator. The system then sends the visit data to the IoT platform via a Wi-Fi connection and returns to the sensor reading process [16, 13].

3.5 Schematic System (Wiring Diagram)

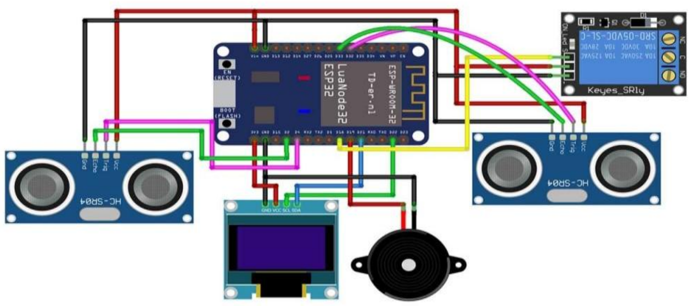

Figure 4. Schematic System (Wiring Diagram) of ESP32-Ultrasonic Based Patient Visitor Counter
Source: Authors' design based on ESP32 and HC-SR04 technical specifications [16], [22].

Table 3. ESP32 connection to HC-SR04 Ultrasonic Sensor.

Sensor	Pin Sensor	Pin ESP32
Sensor 1 (IN)	VCC	5V
Sensor 1 (IN)	GND	GND
Sensor 1 (IN)	TRIG	GPIO 32
Sensor 1 (IN)	ECHO	GPIO 33
Sensor 1 (IN)	VCC	5V
Sensor 2 (OUT)	GND	GND
Sensor 2 (OUT)	TRIG	GPIO 25
Sensor 2 (OUT)	ECHO	GPIO 26

Source: Authors' wiring design.

Table 4.ESP32 connection to 16x2 12C LCD.

Pin LCD I2C	Pin ESP32
VCC	5V
GND	GND
SDA	GPIO 21
SCL	GPIO 22

Table 5.Connection to Buzzer.

Pin Buzzer	Pin ESP32
Positive	GPIO 27
Negative	GND

Source: Authors' wiring design.

In this schematic, the ESP32 DevKit V1 is specified as the central processing unit. Sensor 1 is assigned to inbound detection (TRIG GPIO 32; ECHO GPIO 33), while Sensor 2 is assigned to outbound detection (TRIG GPIO 25; ECHO GPIO 26). The 16×2 I2C LCD uses SDA GPIO 21 and SCL GPIO 22, and the buzzer is assigned to GPIO 27. These connections constitute the proposed wiring specification and have not been validated through electrical or field testing in this study. A future prototype should also address the ESP32's 3.3 V logic requirements when interfacing with 5 V HC-SR04 echo signals and should use appropriate level-shifting or voltage-divider protection where required

3.6 LCD Display Design

Figure 5. 16x2 LCD Display Design
Source: Authors' design based on the proposed information-display requirements [3].

Figure 5 specifies a compact LCD layout for displaying the proposed visitor-flow variables. The first line displays inbound and outbound counts, while the second line displays the calculated current queue/occupancy value. The layout is intended to support rapid interpretation by registration staff and RMIK students. The displayed values are design variables and should not be interpreted as measured results.

Line 1 (16 characters):
text
In:XXX Out:XXX
Line 2 (16 characters):
text

Queue:XXX

This format allows registration staff and students to easily monitor the number of patients queuing at the registration counter. This display provides the following information: Number of patients who have entered the registration area (Incoming)
Number of patients who have left the registration area (Outgoing)
Number of patients currently in the registration/queuing area (Antre) [19].

3.7 Discussion

3.7.1 Comparison with Existing Systems

The comparative state-of-the-art analysis indicates three complementary research streams. First, people-counting studies establish the feasibility of ultrasonic, infrared, and computer-vision sensing [3-4]. Second, healthcare IoT studies demonstrate that ESP32 can support patient-flow and queue-management functions [5]. Third, health-information education studies show that simulation and technology-supported learning environments can strengthen students' informatics competencies [7], [8]. The proposed system sits at the intersection of these streams. Its intended value is not superior sensing performance, but the integration of an understandable embedded-system example into the operational context that RMIK students need to understand.

3.7.2 Comparison with Existing Systems

The educational component is supported by prior evidence that simulation-based learning can improve health-information-system skills. [7] reported significant improvement in students' performance in six of eight simulated HIS processes, while Choi et al. [8] examined simulated EHR use as an informatics-learning strategy. These findings support the pedagogical rationale for using a physical embedded-system artifact to demonstrate how sensing events become operational information. In an RMIK laboratory, the proposed counter could be used to discuss registration workflow, event data, queue indicators, data transmission, and the boundary between operational counters and official patient records. Such use is a proposed educational application and has not yet been evaluated with students in this study.

3.7.3 Comparison with Existing Systems

A physical prototype should be evaluated before any claim of system effectiveness is made. At minimum, future validation should report detection accuracy, counting error, response latency, effective detection distance, repeated trials, inbound/outbound classification accuracy, and failure scenarios such as simultaneous entry, simultaneous exit, close-following pedestrians, stationary objects, and sensor interference. Testing should be conducted under representative registration-area conditions and should compare automated counts with a manually verified reference count. These measures would convert the present conceptual contribution into an experimentally validated engineering study.

3.8 Study Limitations

The main limitation is the absence of physical prototype implementation and empirical testing. Therefore, this study cannot establish numerical accuracy, reliability, latency, or robustness. In addition, the proposed queue value assumes that every detected movement corresponds to a single patient and that movement events are not missed or duplicated. Real registration environments may involve companions, staff, groups of people, or overlapping trajectories that require more advanced sensing or classification. These limitations define the next stage of research rather than weaknesses that can be resolved through conceptual diagrams alone.

The principal result of this study is a coherent conceptual architecture that links non-contact movement sensing, embedded processing, local visualization, and a future IoT layer to the workflow of a healthcare registration area. This is different from claiming that a new counting technology has been invented. Ultrasonic visitor counting and ESP32-based IoT monitoring have already been demonstrated in other contexts [3], [6]. The contribution here is the application context: the architecture is specified around patient-flow monitoring at registration and simultaneously framed as a practical RMIK learning artifact.

Compared with camera-based approaches, the proposed ultrasonic configuration can be conceptually simpler and less dependent on image processing and lighting conditions. However, it also has important limitations: ultrasonic sensing may be affected by sensor placement, target geometry, simultaneous movement, and multiple people passing close together. These limitations are why the current design should not claim accuracy before physical testing. By comparison, [4] evaluated a camera-based ESP32 system across different lighting conditions, while Setiawan et al. [3] performed prototype testing of an ESP32-ultrasonic counter and reported a 1% error. The present study provides the architecture necessary for a similar validation program but does not yet provide those empirical measurements.

4. CONCLUSION

This study produced a conceptual design of an ESP32-HC-SR04 visitor-counting system for healthcare registration and proposed its use as a practical learning medium for RMIK students. The design includes a registration-area layout, block diagram, flowchart, wiring specification, and LCD display concept. The architecture is intended to distinguish inbound and outbound movement from the sequence of two ultrasonic sensors, calculate a conceptual current-occupancy value, provide local feedback, and support future IoT transmission.

The contribution should be interpreted as application-oriented conceptual integration rather than technological novelty in ultrasonic people counting. The ESP32 provides a practical embedded platform with Wi-Fi capability, while the ultrasonic sensors provide a non-contact sensing mechanism suitable for a low-cost laboratory demonstrator. However, because no physical prototype was implemented and tested, the study does not validate detection accuracy, counting error, response latency, detection distance, inbound/outbound classification accuracy, or reliability.

Future research should construct the prototype and conduct repeated controlled and real-world trials, compare automated counts with manually verified counts, test failure scenarios, evaluate IoT transmission, and assess the device's educational usefulness with RMIK students. Integration with a formal health information system should only be considered after the counting function and data-governance requirements have been validated. Thus, the present manuscript establishes the conceptual and educational foundation for subsequent engineering validation.

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