Research by Experimentation for Dependability on the Internet of Things

# D-4.1 – Report on Use Case Definition and Requirements

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**Abstract** This document presents four candidate Internet of Things use cases that are going to be analyzed for their dependability requirements. The use cases encompass a range of typical Internet of Things applications designed for different operating environments and dependability requirements: (1) Outdoor Parking Management, (2) Civil Infrastructure Monitoring, (3) Condition Based Maintenance, (4) Ventilation on Demand. We analyze the potential impact of environmental variations on the dependability requirements of each use case, in terms of data loss, latency and operational lifetime. The primary environmental factors we consider are temperature and radio interference.

## Disclaimer

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# Executive Summary

This deliverable was created in the context of Task 4.2 *Use Case and Requirements* of WP4 *Experimentation and Applications*. It identifies a set of typical Internet of Things (IoT) applications that are exposed to challenging environments and that need to meet given dependability requirements. This deliverable presents four candidate use cases encompassing a range of typical IoT applications designed for different operating environments with different dependability requirements:

1. Outdoor Parking Management,
2. Civil Infrastructure Monitoring,
3. Condition Based Maintenance,
4. Ventilation on Demand.

To facilitate the identification of dependability requirements, we compiled a generic list of characteristics of interest that describes factors that will be taken into account during the design, implementation, and evaluation of the chosen RELYonIT use case implementation.

Based on these characteristics of interest, each of the four applications is studied in detail. The potential impact of environmental variations on the dependability requirements of each use case is analyzed in terms of data loss, latency, and operational lifetime. For each application, we consider a set of different typical climates. The primary environmental factors we consider are temperature and radio interference.

 

# 1 Introduction

## 1.1 Purpose of this document

The main purpose of this document is to present a set of industry applications and their respective dependability requirements as possible use cases for the project. These applications operate under a wide variety of environmental conditions that pose different challenges to dependability. We intend to use this document to establish relations between these environmental conditions and the respective dependability requirements.

## 1.2 Scope of the document

This deliverable is the outcome of Task 4.2 *Use Case and Requirements*. Knowledge gained from this task will serve as the foundation for the generation of models (Tasks 1.1, 1.2, 1.3), protocols (Tasks 2.1, 2.2), and for protocol selection and configuration (Tasks 3.2, 3.3). One of the proposed use cases will later be selected for implementation in Task 4.3 *First Integrated Experiment*.

## 1.3 Use cases overview

We provide an overview of four industry Internet of Things (IoT) applications, which have diverse dependability requirements and cover a large spectrum of environmental conditions.

The first use case is a *Smart Parking* system, a central component of future Smart Cities. Today, vehicles looking for a free parking spot account for more than 30% of the traffic in EU cities. A smart parking system provides real-time information about free parking spots to drivers, by aggregating spot occupancy information from individual sensors. Road traffic can be reduced considerably if such information can be disseminated to drivers accurately and timely.

The second application is located in the area of *Civil Infrastructure Monitoring*. The market for construction site monitoring is undergoing a major shift to 24/7 solutions. Examples include monitoring of bridges for stress and vibration and monitoring buildings for torsion, deformation, and others properties. Main success factors of a monitoring system include (1) providing a complete, end-to-end monitoring solution; (2) being affordable, thus allowing for large-scale monitoring of critical construction points; and (3) integration of data analysis and prediction tools with data captured from other products, thus providing unprecedented insights into the structures under monitoring.

The third use case we present is concerned with *Condition Based Maintenance*. Due to productivity and cost considerations, maintenance procedures of industry mechanic equipments are ideally carried out just in time before a fatal fault is allowed to occur due to, e.g., metal fatigue. The common current practice is using wired sensors to detect anomalies on running equipments and alerting maintenance staff of an upcoming failure. Such solutions are often based on costly and proprietary licensed technologies. In order to lower costs, we want to use open wireless sensors standards. We therefore need to construct a network that delivers messages at the same high data rate and in a timely matter as the wired system. In addition, real-time comparison of data from multiple sensors is needed.

The last use case is a *Ventilation on Demand* system in residential apartments and industrial factories. Autonomous control of ventilation cycles ensures a healthy and comfortable living environment for inhabitants or workers, while reducing energy use during vacancy periods. This application does not have the same level of harsh environmental conditions and reliability requirements than in the previous case, but has more frequent dynamics in a continuous sensing and actuation control loop.

 

# 2 Use Cases Analysis

## 2.1 Formal Analysis Structure

We analyze the four use cases in a uniform structure. Each use case description comprises: (1) a general functionality overview, (2) a description of typical environmental conditions, (3) a list of characteristics of interest, and (4) a table of specific dependability requirements.

### 2.1.1 Characteristics of Interest

In spite of the diversity of the candidate use cases, we try to analyze and understand their characteristics using a uniform set of technical features and constraints. The following list comprises factors that will be taken into account during the design, implementation, and evaluation of the chosen RELYonIT use case implementation.

**Critical Quality of Service Requirements** Any critical QoS requirement, e.g., a maximum latency threshold, which is absolutely needed for the proper operation of the application. Such requirements are prioritized in the design of our dependable IoT.

**Impact on Quality of Service** We try to identify potential impact by environmental factors, e.g., temperature changes and radio interference on certain quality of service properties. We provide qualitative estimations about which QoS properties will degrade when certain environmental condition occur.

**Different Phases of Activity in the Environment** Any discernible time pattern whereby certain environment factors alter their level or intensity radically. Certain use cases might involve regular alternations between busy and idle phases, e.g., peak hours of human activities during the day.

**Indoor / Outdoor** Whether the deployment site is indoor or outdoor often leads to a clear implication about the range of temperature change and intensity of radio interference.

**Size (geographical and topological)** Deployment size in terms of area and number of nodes. Network complexity tends to be positively correlated to deployment size. A large network thus poses extra challenges to multi-hop routing and reproduction of tests.

**Scalability** The flexibility of expanding or shrinking the number of nodes while maintaining the same system functionality. A small scale, initial deployment with the flexibility to be expanded later often benefits the development process, because a higher number of design iterations are permitted.

**Repeatability** Considerations about the repeatability of the environmental conditions (Are they unique for each scenario instance? Are they repeatable?).

**Control of environment** Means and degree that environmental factors can be controlled. A high degree of control enables precise recreation of environmental conditions across multiple test runs. Accurate control of individual environment factors, e.g., temperature, helps to differentiate impacts brought about by different factors. The IoT system's dependability under certain severe conditions can only be fully tested after the condition is held stable for a long enough time period; therefore a good control of the primary environment factors is needed in order to fulfill the test condition for such stress tests.

**Reproducibility in testbeds** Feasibility of reproducing a use case's function and environmental conditions in a testbed. This can potentially be used to conduct small scale experiments.

**New or existing deployment** Whether the use case is going to be deployed from scratch or retrofitted to an existing deployment.

**Access to Deployment Site** Considerations about the access to the deployment site, as well as working conditions.

**Node mobility** We assume all or the majority of sensor nodes are static. Special measures might be needed nonetheless, in order to accommodate a small number of mobile nodes, depending on their motion pattern.

**IP connectivity per individual sensor** Here we consider if the connection with the Internet is going to be only in the gateway or if we need an IP address for each sensor node. A gateway solution puts extra responsibility on the gateway node for protocol translation, while relieving the sensor nodes from running an IP stack.

**Available radio spectra** Considerations about possible constraints and preferences on radio bands to be used for network communication. The 2.4 GHz ISM band supports higher data rate than the 868 MHz ISM band; but the latter is less congested and usually has a longer communication range.

### 2.1.2 Dependability Requirements

The requirements are divided into two separate categories. One category contains the requirements related to the reliability of the application while the other category is concerned with the operational lifetime. The specification of the requirements follows the structure presented in Table 2.1.

Table 2.1: Requirement Template

| | |
|---|---|
| **ID** | Alphanumeric identifier |
| **Name** | Name |
| **Description** | Textual description |
| **Priority** | M (must) / S (should) / C (could) / W (won't have) |
| **Failure Effect** | Possible consequences if we do not comply with this specific requirement |

 

The ID field is the identification which is going to help us to identify the requirements throughout the document and the project (e.g., in WP4). The first letters of the ID indicate the use case to which the requirement refers.

The description will avoid to say anything about *how* the developer should implement the requirement but instead will describe the desired result.

Traditionally, requirements are divided into functional and non-functional. In this case there is little point in this division, given that such requirements are related to dependability, all of them will be non-functional.

The prioritization employs the MoSCoW prioritization technique [5]. This technique divides the requirements into four categories:

**Must.** Requirements labeled as *Must* have to be fulfilled by the system to consider the project successful. It can also be considered as an acronym of **M**inimum **U**sable **S**ubse**T**.

**Should.** Such requirements are still important but are less critical for overall project success. Alternative ways of meeting the specified need may be available.

**Could.** This type of requirement increases customer satisfaction at little costs but they are not critical for project success.

**Won't have.** These requirements are not going to be implemented in the current project, but they may be taken into account for further developments.

## 2.2 Outdoor Parking Management

In the Smart cities context, we target a smart parking solution. Vehicles looking for a free parking spot are responsible for more than 30% of the traffic in EU cities. Autonomous smart parking solutions could significantly reduce the traffic by directly impacting on the users and the ability to easily find a free parking spot.

Parking availability and cars seeking for a free parking spot (known as hustle bustle traffic) are considered as one of the most important actors in traffic congestion in urban areas. However, parking is one of the fundamental services for the inhabitants, commuters or visitors to the city, which has to be taken into account for managing authorities for traffic regulation. Many European cities have been suffering the chronic shortage of parking, especially in the city center. Even now, we can see many public spaces to be occupied by private vehicles for usage as parking lot.

### 2.2.1 Description

We present a general view of the communication infrastructure for a smart parking solution. Normally the sensors for parking detection are embedded into the ground in the center of each parking spot. The sensor nodes should communicate parking space availability to neighboring sensors until they reach the gateway. Multi-hop routing needs to be used when direct contact with the gateway cannot be made.

 

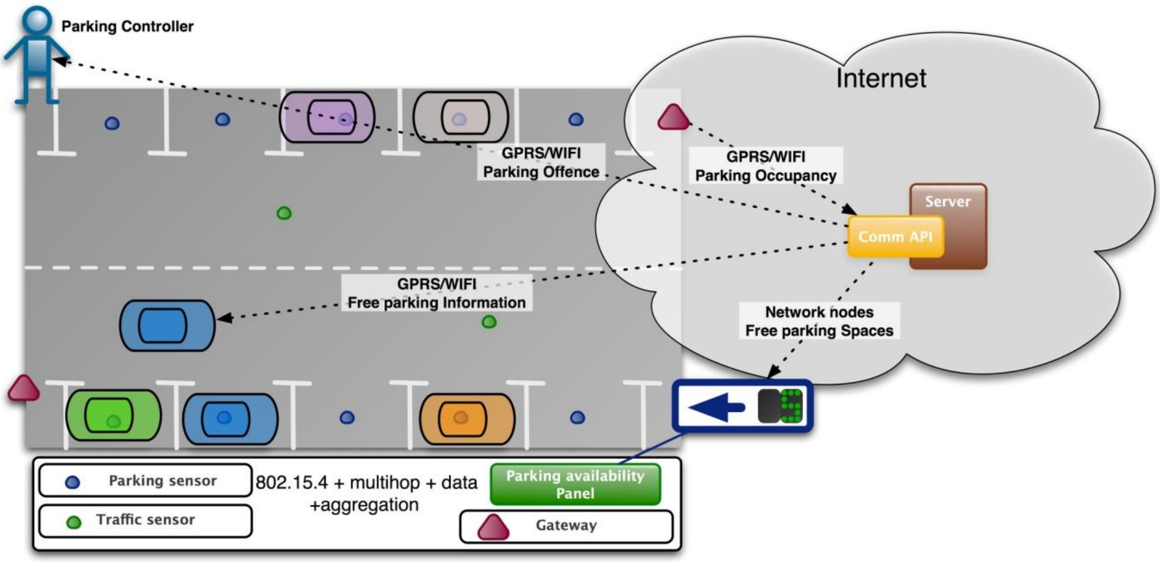


Figure 2.1: Architecture of the parking space availability control service.

A centralized control system stores and processes all data gathered from sensors resulting information and implemented services are offered to citizens by means of mobile applications and city panels.

The parking control application consists of the following main sensor/actuator systems:

- Sensor Nodes, which are small-embedded devices containing an Anisotropic Magneto-Resistive (AMR) MEMS sensor, a low-power IEEE 802.15.4 wireless interface for communication and a suitable battery pack. These nodes are connected to a self-organizing network, which allows communication among the nodes. As cars will usually cover the sensor and severely impact radio connectivity, redundancy of communication needs to be assured in order to enable reliable communication. The sensor nodes must be fully embedded in the road surface to avoid vandalism and destruction by snow cleaning machines. Sensor nodes are on average separated 5 m resulting in a dense topology. The expected lifespan of the sensors should be above four years in optimal conditions to match the interval in which the tarmac is usually replaced in cities. Nevertheless, customers are currently willing to accept more frequent battery change, if needed. Power considerations, environmental considerations and duty cycling timings are presented in the Table 2.3. Moreover, cost considerations should be taken into account for commercial products.

- Hybrid Gateways collect information about parking availability from sensor nodes on the streets and transmit this information to the centralized urban control. They allow interconnection using different interfaces in order to be easily adapted to different urban scenarios. They might be equipped with 3G modems, 802.11 interfaces, or Ethernet interfaces. Taking the resulting higher power consumptions into account, appropriate energy harvesting solutions may be considered. Gateways are located on traffic lights or trees.

 

Table 2.2: Smart parking sensor characteristics

| **Characteristics** | **Description** |
|---|---|
| Dimensions (Hx0) | Circular, 130mm x 80 mm (100 mm x 50mm inner) |
| Antenna type | Fractal matched at 868MHz, SMA connector |
| Battery type | 7200mAh@3.6V |
| Smart sensor interface | TBD |
| Frequency of communication | 868MHz |
| Communication range | 15 m with car, 50 m without car |

Table 2.3: Power requirements for smart parking solution

| **Parking sensor component** | **Power Consumption** | **Operation time** | **Duty cycle** |
|---|---|---|---|
| Radio transceiver | 45 mW-150 mW | 1-5 ms | 0.1%-1% |
| $\mu$C | 12 mW-150mW | 1-5 ms | 0.1%-1% |
| Sensor | 20mW-30mW | 2ms | 0.1% |

- Information Panels collect parking availability information from the control center and display this information to guide drivers to free parking spots. They may also include appropriate energy harvesting solutions.

The sensor nodes consists of the elements described in Table 2.2. In order to function properly, the system has the power requirements described in Table 2.3. In Table 2.4 the environmental variables potentially affecting the smart parking system scenario are presented.

### 2.2.2 Environmental Scenarios

Three different sub-scenarios are summarized, each one with different ambient temperatures:

#### Mediterranean City

Near the Mediterranean sea, a city such as Barcelona usually features an average annual temperature about 20℃ during the day and 11℃ at night. In the coldest month, typically the temperature ranges from 10 to 17℃ during the day and 2 to 10℃ at night. In the warmest month, the temperature ranges from 25 to 31℃ during the day and about 20℃ at night [2, 12].

#### European Continental City

A European continental city such as Moscow has cold winters and mild summers: Temperature variation between night and day and winter and summer are about -12℃ on winter nights to +23℃ on summer noon [4, 14].

#### Desert Climate City

A desert city as Cairo is considered. In this climate, summer is hot and humid with temperatures from 20℃ to 40℃. Winter temperature ranges from 9℃ to 29℃ [3, 13].

 

Table 2.4: Environmental Conditions for Smart Parking.

| Variable | Min | Typ. | Max | Comment |
|---|---|---|---|---|
| Temperature | -30 °C (we have observed down to -14 °C in Moscow during winter). | 0-12 °C Winter, 5-25 °C Autumn, and Spring. 20-50 °C Summer time | +75 °C (we have observed up to +68 °C in south of Spain during summer under direct sun exposure). | - |
| Vibration&Shock | Streets are subject to constant vibrations centered at around 4-7 Hz, few nm/s. | Cars passing and car motion generates vibrations up to 100 Hz and several mm/s. | Sensors may be subject to impact and shock from cars, load, and unload operations. | - |
| Magnetic radiation | Small towns and unpopulated areas show no magnetic disturbances. | Urban scenarios show DC magnetic disturbances mainly attributed to Metro and power stations. | In specific areas, very high magnetic noise will be present. Includes DC and AC components. AC are centered at 50Hz, 60Hz, 100Hz. | It effects detection performance and hence battery consumption and processing capabilities. |
| Humidity | No humidity, very dry environments. | 45-70%, dry or wet ground. | Snow covering sensors or rain. | We have observed strong effects of water on communications. |
| Car rotation | During night almost no movement. 1 car per 5h on average. | Normally in central zones we observe 3-4 cars per hour. | We have observed in very central areas, rotations above 10 cars per hour. | It is also important to consider the traffic around sensors. In centric it might be very dynamic |

 

### 2.2.3 Characteristics of Interest

**Critical QoS requirements** The most critical requirement in this case is the latency of the network, in terms that an event sent by a mote must arrive at the central server in time of seconds.

**Impact on Quality of Service** It is expected that most of the variations in environmental variables are going to be changes in temperature and humidity. Added to this we should consider the fact that the node is embedded inside the road surface so the electromagnetic wave has to be powerful enough to trespass the tarmac.

**Different Phases of Activity in the Environment** Changes in activity will follow a day-night cycle, because usually traffic movement is less frequent at night.

**Indoor / Outdoor** Outdoor.

**Size (geographical and topological)** Tens/Hundreds. We can consider aggregations of tens of motes covering house blocks.

**Scalability** For parking slots, the measures will be independent from each other. But multi-hop radio protocols usually limit the maximal diameter of the network (number of hops a packet can travel).

**Repeatability** Although cities in the world are located in very diverse climates, we assume that our three different scenarios cover the most typical climates and temperature ranges. It should not be too difficult to have a controlled environment like we presented in the sub-scenarios.

**Control of environment** We must consider, in addition to the typical conditions of any urban environment, that the motes are below parking slots. Communication is affected by the need for signal transmission through thin layers of concrete and cars, the presence of metal structures, and wet environments (oil, water). Nevertheless, we do not expect any severe problems in controlling these effects in our experiments.

**Reproducibility in testbeds** We do not perceive any difficulty in reproducing any of the environmental conditions in a lab environment.

**New or existing deployment** WOS has some deployments in different urban environments and climates suitable to use as testbed.

**Access to Deployment Site** The access to any mote is guaranteed but usually a city permission is needed to cut streets. In most cases, we could be supported by city employees.

**Node mobility** We can assume everything is static.

**Link to Internet** There is no need for the nodes to have their own IP address.

**Available radio spectra** As the electromagnetic spectrum is very crowded, it is necessary to select an available and suitable frequency for each specific location. The selection is usually limited to the unlicensed industrial, scientific and medical (ISM) radio bands as published by the ITU [6].

 

### 2.2.4 Dependability Requirements

| | |
|---|---|
| **ID** | SP-1 |
| **Name** | Latency < 30 seconds |
| **Description** | The system has to have a time response in less than 30 seconds. Time response is considered as the time between a car change is detected by a mote and data is received by the Gateway. |
| **Priority** | M |
| **Failure Effect** | A driver could reach, thanks to the system, to a place that is already occupied losing confidence in system, if this situation recurs. |

| | |
|---|---|
| **ID** | SP-2 |
| **Name** | Latency < 10 seconds |
| **Description** | The system should have a time response in less than 10 seconds. Time response is considered as the time between a car change is detected by a mote and data is received by the Gateway. |
| **Priority** | S |
| **Failure Effect** | A driver could reach, thanks to the system, to a place that is already occupied losing confidence in system. |

| | |
|---|---|
| **ID** | SP-3 |
| **Name** | Data loss < 10% |
| **Description** | The system does not lose more than 10% of the events |
| **Priority** | M |
| **Failure Effect** | System could give wrong information too often. |

| | |
|---|---|
| **ID** | SP-4 |
| **Name** | Data loss < 5% |
| **Description** | The system should not lose more than 5% of the events |
| **Priority** | S |
| **Failure Effect** | System could give wrong information sometimes. |

| | |
|---|---|
| **ID** | SP-5 |
| **Name** | Data loss < 1% |
| **Description** | The system could not lose more than 1% of the events |
| **Priority** | C |
| **Failure Effect** | System could not have reduced quality of service. |

The previous information allow us to establish the following requirements regarding the operational lifetime:

| | |
|---|---|
| **ID** | SP-6 |
| **Name** | Battery Life > 6 months, Mediterranean city climate |
| **Description** | Battery has to last for at least 6 months in a climate as described for a Mediterranean city. |
| **Priority** | M |
| **Failure Effect** | System could not be installed due to the effort required in maintenance. |

| | |
|---|---|
| **ID** | SP-7 |
| **Name** | Battery Life > 4 months, European continental city climate |
| **Description** | Battery has to last for at least 4 months in a climate as described for a European continental city. |
| **Priority** | M |
| **Failure Effect** | System could not be installed due to the effort required in maintenance. |

| | |
|---|---|
| **ID** | SP-8 |
| **Name** | Battery Life > 3 months, desert city climate |
| **Description** | Battery has to last for at least 3 months in a climate as described for a desert city. |
| **Priority** | M |
| **Failure Effect** | System could not be installed due to the effort required in maintenance. |

| | |
|---|---|
| **ID** | SP-9 |
| **Name** | Battery Life > 1 year, Mediterranean city climate |
| **Description** | Battery should last for at least 1 year in a climate as described for a Mediterranean city. |
| **Priority** | S |
| **Failure Effect** | System could not be competitive enough due to maintenance cost. |

| | |
|---|---|
| **ID** | SP-10 |
| **Name** | Battery Life > 8 months, European continental city climate |
| **Description** | Battery should last for at least 8 months in a climate as described for a European continental city. |
| **Priority** | S |
| **Failure Effect** | System could not be competitive enough due to maintenance cost. |

| | |
|---|---|
| **ID** | SP-11 |
| **Name** | Battery Life > 6 years, desert city climate |
| **Description** | Battery should last for at least 6 year in a climate as described for a desert city. |
| **Priority** | S |
| **Failure Effect** | System could not be competitive enough due to maintenance cost. |

| | |
|---|---|
| **ID** | SP-12 |
| **Name** | Battery Life > 2 years, Mediterranean city climate |
| **Description** | Battery could last for at least 2 years in a climate as described for a Mediterranean city. |
| **Priority** | C |
| **Failure Effect** | System could not be the ultimate one. |

| | |
|---|---|
| **ID** | SP-13 |
| **Name** | Battery Life > 1.5 years, European continental city climate |
| **Description** | Battery could to last for at least 1.5 years in a climate as described for a European continental city. |
| **Priority** | C |
| **Failure Effect** | System could not be the ultimate one. |

| | |
|---|---|
| **ID** | SP-14 |
| **Name** | Battery Life > 1 year, desert city climate |
| **Description** | Battery could last for at least 1 year in a climate as described for a desert city. |
| **Priority** | C |
| **Failure Effect** | System could not be the ultimate one. |

## 2.3 Civil Infrastructure Monitoring

The Spanish normative regulation "Código Técnico de la Edificación" (Technical Building Code) states that the goal of civil infrastructure monitoring will be to detect any damage or abnor-

 

Figure 2.2: Application of stress on a rafter.

malities at an *early* stage, in order to take appropriate measures for mitigating risks before an unwanted event occurs [7].

When we want to monitor the effect of specific conditions on a structure under construction, there are mainly two types of test procedures: in testbeds and directly on the structure. The measurement can be done by piezoelectric gauges embedded into the concrete. In place monitoring with embedded sensors can, for example, be used as a safety system. The stresses to which a structure is subjected at the time of construction are constantly measured and compared with a theoretically determined maximal threshold. If this threshold is reached, the operation can be stopped before any accident might happen. As a concrete example, we can consider the monitoring of the load on the pillars, when the bridge deck is sliding on these, during the construction process.

In contrast, testbed experiments do not directly measure the effects in situ, but replicate measured forces to which the structure is subjected on a similar specimen in a lab. The replicated specimen can be a simple sample of material inside a testbed or a full replica of the original part. To generate meaningful results, the material of the replica must be the same as the one of the structure (e.g., the same concrete). To ensure this, the replica are usually manufactured simultaneously with to the original (Figure 2.2).

### 2.3.1 Description

When we monitor a structure, we should consider that the structure perhaps is currently surrounded by an urban ecosystem (with some of the features to take into account that are the same as in the *Smart Parking System* case).

A need to in parallel monitor the construction parts as well as the surrounding structures is not uncommon, for example, in metro works, slope stability monitoring, bridge monitoring, and tunnels monitoring. In the specific case of metro works (Figure 2.3), partner WOS offers a particular product. A scenario in which this product can be applied is the following: The route of a new metro network is located close to a street at the bottom of a natural escarpment, with many old historic buildings. In such a construction project located in a densely populated urban

 

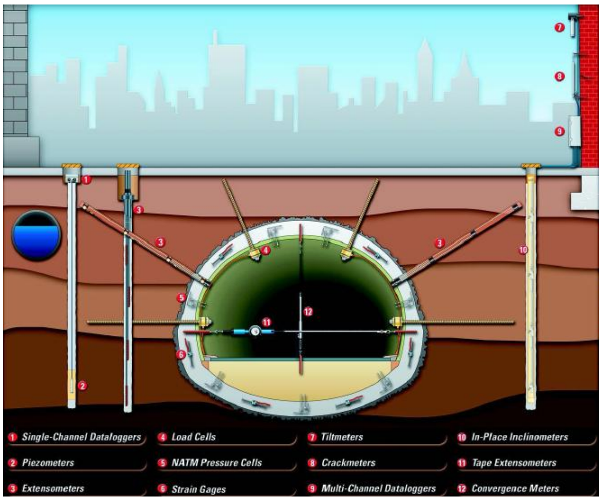


Figure 2.3: Underground infrastructure monitoring.

area with multiple independent private properties to be monitored, a conventional hardwired system would not be practical, so the novel wireless loggers are key to the success. These wireless loggers consist of tilt meters and crack meters connected to wireless Loadsensing (LS) dataloggers. The LS dataloggers communicate every few minutes with a gateway sited nearby, which automatically transmits the data via a 3G modem to a computer running user-friendly LS software at the client's offices. The data is also transmitted to a web site at regular intervals, enabling instant data access to any member of the contract team, without the need for the client to have either a dedicated computer or engineer. In the event that pre-set limits are exceeded, nominated personnel can be alerted by SMS text message and email. This kind of monitoring requires two types of artifacts:

- Wireless multi-channel LS dataloggers in each building and in each tunnel section.
- Gateways to collect, store, and send the data via 3G or Wi-Fi. One in the affected street for dataloggers at buildings, and one at each end of the tunnel for the dataloggers inside of the tunnel.

The expected environmental conditions for this use case are described in Table 2.5.

### 2.3.2 Characteristics of Interest

**Critical QoS Requirements** In this scenario, typically not the sensor value itself but the gradient between sensor values are of interest. Thus, it is of paramount importance not to lose measurements in order not to make wrong decisions. The latency of the system, although it is desirable to be low, it is not of paramount importance, given that we need to anticipate the events long before they happen. With low latencies, the monitoring system could also be used as an emergency alert system.

 

Table 2.5: Environmental Conditions for Smart Infrastructure.

| **Variable** | **Min** | **Typ.** | **Max** | **Comment** |
|---|---|---|---|---|
| Temperature | -40 °C (we have observed down to -27 °C in Austria during winter). | 0-12 °C Winter, 5-25 °C Autumn and Spring, 20-50 °C Summer time. | +85 °C (we have observed up to 70 °C in Qatar during summer under direct sun exposure). | Temperature range depends on the region of interest. Rapid temperature changes may occur if a sensor under direct sunlight exposure is covered. Note that temperature effects shows day-night cycles. |
| Vibration&Shock | Sensors are exposed to civil works risks. Normally they are subject to constant vibrations and shocks as well as wind gusts. | Sensors installed in bridges, slopes, or structures might be affected by wind, structure vibration. | In extreme situations such mining or tunneling, sensors may suffer strong impacts during tunneling operations. | – |
| EM radiation | No EM radiation effects. | EM radiation form DC and AC sources such power lines and machinery. | In harbors, airports, mines radiation from Radars, frequency jammers and Wi-Fi and radios may interfere with communications. | It affects detection performance and hence battery consumption and processing capabilities. |
| Humidity | No humidity, very dry environments. Might have effects on electronics. | 45-70%, dry or wet normal operation. | Snow covering sensors or strong rain or flooding. | Strong effects of water on communications have been observed. |

**Impact on Quality of Service** Although distances between sensors usually do not vary during the deployment time, there may be cases in which changes in the environment might affect connectivity. These changes are planned in advance, so that is is possible to place nodes *a priori* at suitable locations to limit negative effects. Regarding temperature, concrete can reach temperatures up to 70 °C while being forged. If we want to embed nodes in the concrete, the nodes must withstand such temperatures, but nodes could be split into a sensor and a detached communication device to mitigate the issue.

**Different Phases of Activity in the Environment** If we look at the daily cycle, we do not assume phases with lower activity as such constructions sites usually operate 24 h a day in shift operation. If we look at the construction lifecycle, activities and schedules differ from one construction site to another, but these characteristics are well defined at the beginning of the construction.

**Indoor / Outdoor** We have to take into consideration that a typical infrastructure construction site could span both environments, as can be seen in Figure 2.3. sometimes two separate systems (or at least two different networks) are needed – one for the infrastructure itself and one to monitor the surroundings.

**Size (geographical and topological)** At a typical site, we can assume networks of ten nodes for each task and we can assume approximately three different monitoring tasks at a time. Looking at the geographical size, we can assume extensions of less than 100-200 $m^2$, due to the fact that a bigger extension will require the monitoring of more than one structure. An average distance between nodes of 5-10 m can be expected.

**Scalability** The actual construction sites could be as large as 200 $m^2$. The length of one dimension it is rarely more than 50 m. Usually, only part of the construction site needs to be monitored at a specific time interval.

**Repeatability** Despite the fact that there are not two identical infrastructures, we can assume that the phenomena we have to monitor are quite similar. It should not be too difficult to have an useful and controlled environment for each phenomenon.

**Control of environment** To reproduce the conditions that we can find in a civil infrastructure project, we need to have extensions of around tens of meters. We also need to reproduce the presence of large concrete blocks, heavy vehicles with large metal components, and low frequency interference from heavy machinery.

**Reproducibility in testbeds** The previous factors suggest that the lab environment could only be an outdoor one. Despite there being indoor infrastructures constructions which need to be monitored (tunnels), it will be easier to deal with the aforementioned components in an outdoor environment and such environments are also more common.

**New or existing deployment** We have the possibility to use one new deployment as it is the most comfortable way to include new technologies envisioned.

**Access to Deployment Site** It is expected that full access to the monitored parts, at least during the construction, is possible. In many cases the node will be lost after the battery is drained as the recovery is usually not economically worthwhile.

**Node mobility** Although there are situations that require mobility for the monitored element (for instance the arm of a crane), we can assume almost fully static situations in most cases.

**IP connectivity per individual sensors** There is no urgent need for the nodes to have IP connectivity, but this could be used for additional commercial purposes.

**Available radio spectra** The activity sometimes will take place outside, so that one has to consult the specific legislation of each country [6]. Moreover, we should consider that there will be electrical motors which can cause interference, mainly in lower frequencies. At the same time, we need to keep in mind that the electromagnetic wave will go through (reinforced) concrete pieces, which limits the suitable range of the electromagnetic spectrum.

### 2.3.3 Environmental Scenarios

The main environmental factors to be considered are temperature and humidity. We can identify the following different climates:

#### Cold

This climate is the one we can, for example, find in Russia or Austria. This climate is characterized by temperatures that can oscillate between −20 ℃ and up to 30 ℃, with a daily thermal oscillation of less than 10 ℃. The relative humidity in Moscow oscillates from 60% to 85%.

#### Temperate climate

This climate can be found in the Mediterranean (it is also known as cold Mediterranean). This climate can have thermal oscillation from −13 ℃ up to 45 ℃ during the year, and a daily oscillation of 10-15 ℃. We can consider relative humidity similar to the previous one, an oscillation from 65% to 85%.

#### Warm desert climate

Saudi Arabia is an example of this. Here we can find temperatures from 18 ℃ up to 50 ℃. In these environments, we can usually find daily temperature oscillations of around 30 ℃. Humidity in Saudi Arabia goes from 11% of average on July to 46% on December, but sometimes humidity can reach 70%.

 

### 2.3.4 Dependability Requirements

| | |
|---|---|
| **ID** | CI-1 |
| **Name** | Latency $<$ 5 minutes |
| **Description** | The system has to have a time response of less than 5 minutes. Time response is considered as the time between a measurement is made and it triggers a warning signal. |
| **Priority** | M |
| **Failure Effect** | The need for detecting dangerous situations in time to avoid any damage could not be satisfied. 5 minutes is the minimum time to evacuate any work place. |

| | |
|---|---|
| **ID** | CI-2 |
| **Name** | Data loss $<$ 2% |
| **Description** | The system must not lose more than the 2% of the measurements. |
| **Priority** | M |
| **Failure Effect** | In case more data is being lost, we could be overlooking a dangerous situation. |

| | |
|---|---|
| **ID** | CI-3 |
| **Name** | Latency $<$ 1 minute |
| **Description** | The system should have a time response of less than 1 minute. Time response is considered as the time between a measurement is made and the triggering of a warning signal. |
| **Priority** | S |
| **Failure Effect** | We could be unable to fix the problem because of degradation of one specific part. |

| | |
|---|---|
| **ID** | CI-4 |
| **Name** | Data loss $<$ 1% |
| **Description** | The system should not lose more than 1% of the measurements. |
| **Priority** | S |
| **Failure Effect** | We could be unable to study the cause of the collapse. |

With the previous requirements in mind we consider the following requirements:

| | |
|---|---|
| **ID** | CI-5 |
| **Name** | Battery Life > 6 months, temperate climate |
| **Description** | The system has to last for at least 6 months in a temperate climate. |
| **Priority** | M |
| **Failure Effect** | We would not meet the safety period required for leaving the infrastructure with confidence. |

| | |
|---|---|
| **ID** | CI-6 |
| **Name** | Battery Life > 4 months, cold climate |
| **Description** | The system has to last for at least 4 months in a cold climate. |
| **Priority** | M |
| **Failure Effect** | We would not meet the safety period required for leaving the infrastructure with confidence. |

| | |
|---|---|
| **ID** | CI-7 |
| **Name** | Battery Life > 4 months, warm desert climate |
| **Description** | The system has to last for at least 4 months in a warm desert climate. |
| **Priority** | M |
| **Failure Effect** | We would not meet the safety period required for leaving the infrastructure with confidence. |

| | |
|---|---|
| **ID** | CI-8 |
| **Name** | Battery Life > 1 year, temperate climate |
| **Description** | The system has to last for at least 1 year in a temperate climate. |
| **Priority** | C |
| **Failure Effect** | We could not add a quality mark. |

| | |
|---|---|
| **ID** | CI-9 |
| **Name** | Battery Life > 6 months, cold climate |
| **Description** | The system has to last for at least 6 months in a cold climate. |
| **Priority** | C |
| **Failure Effect** | We could not add a quality mark. |

| | |
|---|---|
| **ID** | CI-10 |
| **Name** | Battery Life > 6 months, warm desert climate |
| **Description** | The system has to last for at least 6 months in a warm desert climate. |
| **Priority** | C |
| **Failure Effect** | We could not add a quality mark. |

## 2.4 Condition-Based Maintenance

The goal of condition-based maintenance is to anticipate the occurrence of a fault in advance in order to be able to pro-actively prevent future malfunctions. To achieve that, a predictive maintenance system measures component vibrations, temperatures, or flow rates. With this information, the system can give appropriate hints to prevent a failure.

Condition-based maintenance can enable significant savings in energy (thanks to improvements in spare part logistics) and money (due to a reduction of holding time). In addition, it is possible to increase the efficiency of the machinery and to reduce the need for periodic maintenance.

The advantages of condition-based maintenance are especially effective for large machines like the ones found on commercial vessels (Figure 2.4).

### 2.4.1 Description

The most useful technique for condition-based maintenance is the vibration measurement and analysis. The main advantage in comparison to other approaches such as ink penetration, X-ray, and ultrasound, is the possibility to record measurements while the machines are running.

At coarse-grained approach could use vibration measurements from the external surfaces of the machines, for example, provided by capacity displacement sensors in conjunction with accelerometers. Based on this data, different approaches to detect a future rupture are available. Some significant ones are:

**Spectral Analysis** The essence of the spectral analysis is to decompose the vibration signal into frequency spectrum components. This allows to correlate vibrations with the forces acting within the machinery. If there are some new, unforeseen spectral components, a future rupture could be predicted.

**Waveform Analysis** For example, a sharp peak or a pulse and a continuous signal that varies at random may have spectra that look the same, although the waveforms are completely different. In engine vibration, the peaks are usually caused by mechanical impact, and random noise can be caused by the degradation of bearings in an advanced stage.

**Vibration Phase Analysis** This refers to the analysis of phase difference between horizontal and vertical vibration or between different axial vibrations of the machine support system. It allows to determine the relative motions in the machinery. If something new is seen, it might indicate a future rupture.

Typical devices that may need to be monitored on a vessel can be:

 

Figure 2.4: *Ciudad de Sevilla* Engine Room.

- main and auxiliary diesel engines,
- exhaust gas piping,
- alternators,
- electric appliances and lighting,
- boilers,
- steam and condensate piping, and
- tanks

Large engines are usually located in engine rooms that have the effect of a Faraday cage (Figure 2.4). This makes wireless communication with the outside difficult to impossible. In typical scenarios, most wireless communication will take place inside the engine room. Within these rooms it is possible to find a multitude of metal pieces, in which the electromagnetic wave dissipates upon contact. To make communication possible, it might be necessary to either increase the signal strength (with consequent reduction of battery life) or to take this effect into account when planing the network, so that transmissions could avoid spaces occupied by large metal objects.

Regarding temperature, it is important to consider that, despite the machinery being designed to operate at reasonable temperature values as well as not to heat the surrounding environment too much, in emergency situations – when the measurements are most needed – temperature could rise significantly. Approximately 3% of the machine power is dissipated as heat. This fact can be mitigated using detached probes instead of directly placing the node in intimate contact with the surface of the machinery. As an example, we can consider the *Wärtsilä 46 lubricating oil pump* which has a specified operational temperature of 100 °C [9].

As stated in the paper "A Long-Term Study on the Effects of Meteorological Conditions on 802.15.4 Links" [11], humidity can also have a significant effect on wireless communication.

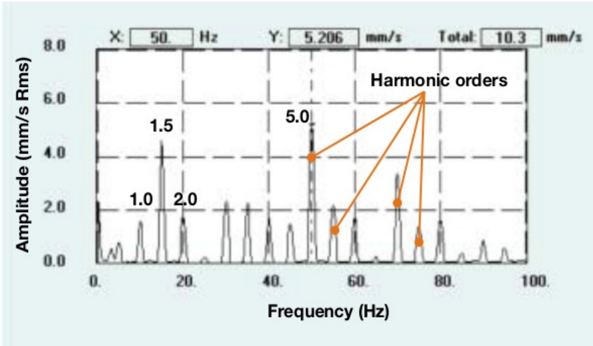


Figure 2.5: Typical displacement of a Diesel engine [10].

This is especially relevant at ships, where we can find significant humidity levels. For example at the injectors coolers, we can find relative humidity of 80% at 35 ℃ [9]. We cannot assume that the humidity just depends on temperature, but we can establish a distinct relationship for each part of the ship.

Environmental requirements of this use case are summarized in Table 2.6.

### 2.4.2 Characteristics of Interest

**Critical QoS requirements** As we need to consider relationships between the measurements, it is mandatory to have precise knowledge of the time of recording for each measurement. This can be either reached by establishing a tight time synchronization among the nodes and time-stamping each measurement, or with a low latency delivery of measurements. Data loss needs to be reasonably low in both approaches.

**Impact on Quality of Service** It seems that the main factor that will affect communications is the presence of large metal components. The network might also be exposed to water vapor and sudden significant temperature changes.

**Different Phases of Activity in the Environment** Changes in activity are not expected during operation of the machines.

**Indoor / Outdoor** Indoor, usually inside a Farady cage.

**Size (geographical and topological)** A high density of nodes is expected. A plausible number could be 5 nodes in $20m^2$.

**Scalability** Different parts and components of a vessel can usually be monitored largely independent, so that a modular design can be considered.

**Repeatability** Exactly similar conditions are usually difficult to replicate for complex machinery. The fact that a large vessel usually has several components of the same type might allow the parallel study of different approaches under roughly comparable conditions.

**Control of environment** Environment conditions are almost entirely determined by the state of machinery, thus we have limited control over it.

 

Table 2.6: Environmental Conditions for Condition-Based Maintenance.

| Variable | Min | Typ. | Max | Comment |
|---|---|---|---|---|
| Temperature [9] | 10 °C (minimum outside temperature could be 0 °C). | In the specification for ventilation in machine "Wärtsilä 46" it is said that "it is recommended to consider an outside air temperature of not less than 35 °C and a temperature rise of 11 °C for the ventilation air". | 50 °C (in emergency cases, the machine is designed to work with incoming air temperatures up to 50 °C). | If the temperature rise over 50 °C, the problems in the combustion would be far greater than a lack of communication among measuring devices. |
| Vibration&Shock | Sensor is not exposed to vibrations. | 5 mm/s RMS (50 Hz). | 10 mm/s RMS (50 Hz). | Data extracted from Guidelines to engine dynamics and vibration (Hannu Tienhaara). It is taken at 50 Hz which is the biggest vibration component. [10] |
| EM radiation | No EM radiation effects. | EM radiation form DC and AC sources such power lines and electric motors. | | It effects detection performance and hence battery consumption and processing capabilities. |
| Humidity | 20-30% | 50-60% | 80% | We have observed strong effects of water on communications. |

**Reproducibility in testbeds** Limited reproduction of the environment in a lab is possible by using smaller comparable machinery, for instance, the Diesel engine of a car. Nevertheless, the size of the machine can have a considerable effect on the results. The full environment is difficult to reproduce in a lab.

**New or existing deployment** Possible deployment sites do not currently employ any wireless sensors.

**Access to Deployment Site** There may be situations in which monitoring is required for inaccessible engine parts and where deployment requires a disassembly of the engine. These situations should be avoided by trying to monitor only parts with easy accessibility, for example, to ease battery replacements. Otherwise, a condition-based maintenance system might require more work than manual maintenance.

**Node mobility** We can assume that all nodes are static.

**IP connectivity per individual sensor** An Internet connection is not constantly available (at least offshore). IP connectivity on the individual nodes is not needed.

**Available radio spectra** As explained above, in most situations the equipment will be located in Faraday cages so that a less constrained selection of frequencies might be possible.

### 2.4.3 Environmental Scenarios

We can consider two separate environments, one representing legal conditions for a working place, and another without this restriction. In these two types of environments, the variation between day and night is small due to the sea cushion effect.

#### With conditions for the stay of a human being

These conditions are as described in most legal documents as temperature between 14 and 25 ℃ and humidity between 30% and 70%.

#### Without the need to support human comfort

In this case, the environmental conditions could be more extreme. It is not unusual to find temperatures from 5 up to 80 ℃ on items that need to be measured. Humidity is usually the same as in the previous case, between 30% and 70%.

### 2.4.4 Dependability Requirements

| | |
|---|---|
| **ID** | CB-2 |
| **Name** | Data loss < 10% |
| **Description** | The system does not lose more than 10% of the measurements. |
| **Priority** | M |
| **Failure Effect** | We could be overlooking a dangerous situation |

| | |
|---|---|
| **ID** | CB-3 |
| **Name** | Latency $<$ 10 seconds |
| **Description** | The system should have a time response of less than 10 seconds. Time response is considered as the time between a measurement is made and the moment this information is processed by the gateway. |
| **Priority** | S |
| **Failure Effect** | We could be unable to detect the failure causes |

| | |
|---|---|
| **ID** | CB-4 |
| **Name** | Data loss $<$ 5% |
| **Description** | The system should not lose more than 5% of the measurements. |
| **Priority** | S |
| **Failure Effect** | We could be unable to detect the failure causes. |

| | |
|---|---|
| **ID** | CB-5 |
| **Name** | Data loss $<$ 1% |
| **Description** | The system could not lose more than 1% of the measurements. |
| **Priority** | C |
| **Failure Effect** | We could be unable to detect the failure causes with accuracy. |

With the previous requirements and considering the operation in a vessel, we consider the following lifetime requirements:

| | |
|---|---|
| **ID** | CB-6 |
| **Name** | Battery Life $>$ 3 months, conditions suitable for human |
| **Description** | The system has to last for 3 months with the same batteries inside an environment with conditions for the stay of a human being. |
| **Priority** | M |
| **Failure Effect** | The attention the system would need, will render it impractical. |

| | |
|---|---|
| **ID** | CB-7 |
| **Name** | Battery Life > 6 months, conditions suitable for human |
| **Description** | The system should last for 6 months with the same batteries inside an environment with conditions for the stay of a human being. |
| **Priority** | S |
| **Failure Effect** | The system could be used, but not extensively. |

## 2.5 Ventilation on Demand

One of the biggest challenges for any European construction company is to comply with the directive 2002/91/EC [8] that states:

> Article 4: Setting of energy performance requirements (...) These requirements shall take account of general indoor climate conditions, in order to avoid possible negative effects such as inadequate ventilation, as well as local conditions and the designated function and the age of the building. These requirements shall be reviewed at regular intervals which should not be longer than five years and, if necessary, updated in order to reflect technical progress in the building sector.

Focusing on ventilation, one of the most efficient approaches is *ventilation on demand*. Using this approach, it is possible to save up to 30% of the energy used in climatisation by reducing the heat exchange between the outside and inside air (Figure 2.6).

### 2.5.1 Description

The relation between comfort and $CO_2$ level is well-known as well as the fact that an over-ventilation does not provide any further benefit but produces a huge amount of energy waste.

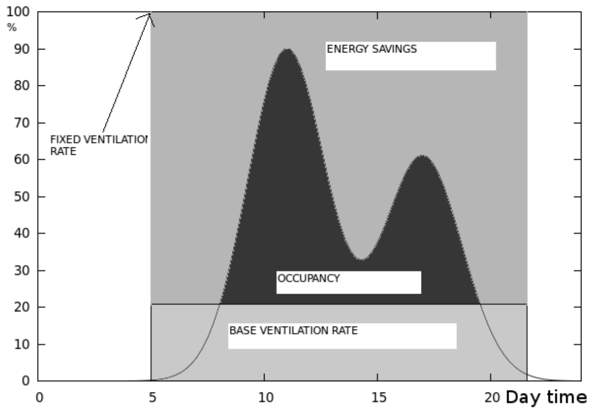


Figure 2.6: Energy savings due to a ventilation on demand system.

Ventilation should have a good compromise between $CO_2$ concentration and energy savings. In order to reach the compromise, we can use a pair of sensor/actuator in which the sensor analyzes the $CO_2$ level, and if the threshold has been reached, the actuator opens the ventilation gate. In this use case we can consider the interference due to domestic equipment as the main obstacle for communication. Table 2.7 summarizes the environmental conditions for the ventilation on demand use case.

### 2.5.2 Characteristics of Interest

**Critical QoS requirements** The most critical factor is data loss. If the system is able to deliver most of the data, we can consider the possibility to use it for safety-critical detection of toxic agents.

**Impact on Quality of Service** It has to be considered that an interference source can initiate its activity during a crucial moment (e.g., when a critical $CO_2$ level is reached or when a toxic agent is released).

**Different Phases of Activity in the Environment** The activity phases that we can encounter inside a house usually are identified with human behavior or with the usual industrial schedule.

**Indoor / Outdoor** Indoor.

**Size (geographical and topological)** two or three nodes per room. The diffusion of gases ensures that levels get equal in a closed space quickly.

**Scalability** The same as in condition-based maintenance. We can assume that scalability should not be a problem as the sub-networks in the individual rooms are largely independent.

**Repeatability** We do not foresee any severe problem in repeating the experiments under similar conditions.

**Control of environment** We can expect to have full control over the environment.

**Reproducibility and in testbeds** No issues are expected in this regard.

**New or existing deployment** ACCIONA has several ventilation on demand systems that are being monitored. Nevertheless, a new one is to be preferred for the sake of flexibility.

**Access to Deployment Site** Trivial.

**Node mobility** It is expected that all nodes are static.

**IP connectivity per individual sensor** There is no need for the nodes to have IP connectivity, but it might enhance the user experience.

**Availale radio spectra** Unfortunately, the 2.4GHz is used by Wi-Fi connections. Despite being the most desirable frequency band, it could be the one with most interference. Anyway, we should consider the specific regulation for each country [6].

Table 2.7: Environmental Conditions for Ventilation on Demand.

| Variable | Min | Typ. | Max | Comment |
|---|---|---|---|---|
| Temperature | 17°C | 22°C | 27°C | Legal values for permanent work places. |
| EM radiation | No EM radiation effects. | EM radiation form DC and AC sources such as power lines and electric motors. | Domestic equipment (Wi-Fi routers, Bluetooth, etc.). | It effects detection performance and hence battery consumption and processing capabilities. |
| Humidity | No humidity, very dry environments. Might have effects on electronics. | 20-30% | 50-60% | These values are those allowed by ASHRAE 55-1981 [1]. |

### 2.5.3 Environmental Scenarios

For this use case we can identify two typical environments, each with its specific environmental conditions and needs:

#### Domestic environment

In this environment the main agent to be measured is the $CO_2$ emitted by people. A daily temperature oscillation from 15 ℃ up to 25 ℃ is expected. The main factor to consider is the interference emitted by domestic equipment such as Wi-Fi routers, Bluetooth devices, and microwave ovens.

#### Industrial environment

This environment usually has higher latency requirements and there is a possibility for a wider variety of agents to be measured, for example, CO, $NH_3$, and suspended particles. The daily temperature variation is wider than in the domestic environment. It is determined by the law for each country (in most of the cases temperature is between 14 and 25 ℃ and humidity between 30% and 70%.). It is expected to encounter less interference sources, but we should also consider heavy machinery as in section 2.4.

### 2.5.4 Dependability Requirements

| | |
|---|---|
| **ID** | VD-1 |
| **Name** | Data loss < 25% |
| **Description** | The system does not lose more than 25% of the measurements. |
| **Priority** | M |
| **Failure Effect** | The user could prefer traditional solutions (e.g., open a window) |

| | |
|---|---|
| **ID** | VD-2 |
| **Name** | Latency < 5 minutes |
| **Description** | The system needs to have a response time of less than 5 minutes. Response time is considered to be the time between a $CO_2$ measurement and the gate opening. |
| **Priority** | M |
| **Failure Effect** | The user could prefer traditional solutions (e.g., open a window) |

 

| | |
|---|---|
| **ID** | VD-3 |
| **Name** | Data loss $< 10\%$ |
| **Description** | The system should not lose more than 10% of the measurements. |
| **Priority** | S |
| **Failure Effect** | There could be situations that would not be treated as needed (e.g., the detection of a toxic agent). |

| | |
|---|---|
| **ID** | VD-4 |
| **Name** | Latency $<$ 1 minute |
| **Description** | The system should have a time response in less than 1 minute. Response time is considered as the time between a $CO_2$ measurement, and the gateway noticing the measurement. |
| **Priority** | S |
| **Failure Effect** | User could initially not feel comfortable after entering the room or the danger of a toxic agent could not be avoided by this system. |

| | |
|---|---|
| **ID** | VD-5 |
| **Name** | Data loss $< 5\%$ |
| **Description** | The system could not lose more than 5% of the measurements. |
| **Priority** | C |
| **Failure Effect** | There could be situations that would not be treated as needed (e.g., the detection of a toxic agent). |

The previous information allows us to establish the following requirements regarding the operational lifetime:

| | |
|---|---|
| **ID** | VD-6 |
| **Name** | Battery life $>$ 6 months, domestic environment |
| **Description** | Battery should last for at least 6 months in a domestic environment. |
| **Priority** | S |
| **Failure Effect** | User would need to change batteries more frequently. |

 

| | |
|---|---|
| **ID** | VD-7 |
| **Name** | Battery life $>$ 8 months, domestic environment |
| **Description** | Battery could last for at least 8 months in an industrial environment. |
| **Priority** | C |
| **Failure Effect** | Industry will be reluctant to use it because of its high maintenance costs. |

| | |
|---|---|
| **ID** | VD-8 |
| **Name** | Battery life $>$ 1 year |
| **Description** | Battery could last for at least 1 year in a domestic environment. |
| **Priority** | C |
| **Failure Effect** | User would need to change batteries more frequently. |

| | |
|---|---|
| **ID** | VD-9 |
| **Name** | Battery life $>$ 1 year |
| **Description** | Battery could last for at least 1 year in an industrial environment. |
| **Priority** | C |
| **Failure Effect** | Industry does not consider the ventilation on demand system as an alternative because of its high maintenance costs. |

# 3 Conclusions

Four different use cases have been described in this document. These include outdoor parking management, structure supervision at constructions sites, condition-based maintenance on vessels, and ventilation on-demand in buildings. At the first stage, these use cases were chosen because they are exposed to challenging environmental conditions and need to meet stringent dependability requirements.

As a result of the work carried out, several dependability requirements have been identified. Special attention has been paid to the possible environmental conditions and their possible effect on the requirements. In order to facilitate the evaluation of the architecture in the coming months, the requirements have been classified in terms of priority.

The requirements defined in this document will be the basis for the activities to be carried out in the remainder of the project.

 

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