A RAMS analysis for a precision scale-up configuration of the 'Smart Street' pilot site: an industry 4.0 case study

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ABSTRACT
In order to develop a scale-up for a 'Smart Street' pilot site, we perform a RAMS analysis: the combination of Reliability Analysis and FMECA helps to identify the best configuration to scale up systems without incurring in marginally reliable configurations, allowing refining an Industry 4.0 Case Study.

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1. INTRODUCTION

The system called *Smart Street* is a public streetlighting line managed in an automatic, programmable way. Its general architecture is shown in Figure 1.

The first part of this document analyses the *Smart Street* pilot site system located at the ENEA Centre in Casaccia (Rome) from a qualitative point of view. The second part examines the scalability of the system to cover 5,000 streetlamps and some final considerations about architectural configurations.

This prediction approach, its trade-offs, and a study of the possible configurations are presented based on the military handbook MIL-HDBK-217, 'Reliability Prediction of Electronic Equipment' [1]-[4], appropriately modified to take account of new physical factors inherent in COTS components. A Failure Mode, Effects, and Criticality Analysis (FMECA) is also performed herein.

1.1. The *Smart Street* system study

In our study, a reliability analysis of the system is performed. Then, in order to preserve or increase the operating time in optimal conditions [5]-[7], the identification of some critical components (at the subsystem or component level) enables the implementation of an inventory stock in order to evaluate the cost effort in terms of time and labour related to maintenance [8]-[11].

The second analysis is a FMECA study [12]-[15], which, through logical sequences of operation, aims to mitigate the severity of the effects of a possible failure at the subsystem or component level [16]-[20].

A synthesis of the two previous methodologies gives us a sort of 'X-ray plate' of the system, highlighting the weak parts or subsystems. All this data is useful for evaluating the logistic efforts in terms of stock, intervention times, and possible maintenance.
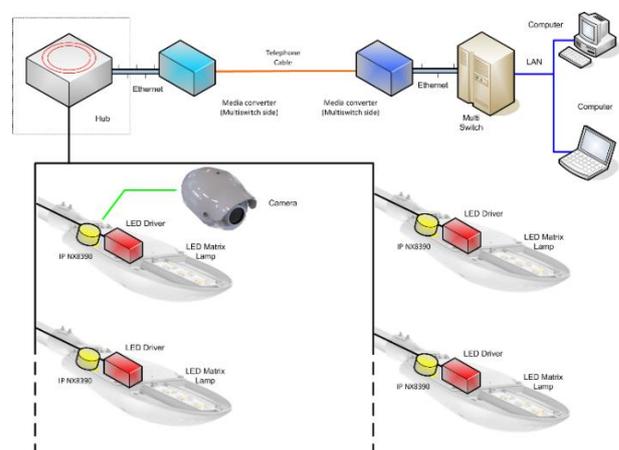
Figure 1. The general architecture of the *Smart Street* pilot site system.

2. THE RELIABILITY ANALYSIS: METHODS AND RESULTS

Reliability predictions are an important tool for making design trade-off decisions and estimating the reliability of the design. They are often used for making initial product support decisions (such as how many spares are required to support the systems). Inaccurate predictions can lead to overly conservative designs and/or the procurement of excessive spare parts, resulting in added life cycle cost [21].

2.1. The failure probability

The failure of a component or system is an event whose occurrence can be examined in two different ways:

a. A casual event, whose causes remain substantially unknown and whose frequency is empirically observed;

b. The results of the chemical-physical degradation processes that evolve during the operation.

In the first case, the probability of failure is considered as the ratio between the occurrences of the observed failures and all executed tests [22]-[25].

The failure probability is calculated as a function of the observed failures, represented by the ratio:

$$\lambda(t) = \frac{-\dfrac{dR(t)}{dt}}{R(t)};$$ (1)

therefore, the expression of the reliability is:

$$R(t) = e^{\int_0^\infty \lambda(t)dt}.$$ (2)

The advantage is that the reliability of each item is easily studied and can be easily applied [26]. The disadvantage is that no information is supplied about the failure mode and therefore about the prognostic for each single item [27]-[28].

In the second case, the probability of failure is realised as the measure of uncertainty of the predictions; therefore, reliability can be calculated as a function of stress-strength relations, including the uncertainty in which the processes can be realised. In this case, a great amount of data and/or studies are needed [29].

We perform the reliability first by using the MIL-HDBK-217 handbook method, but the results are mitigated by factors that take into account degradation processes and environmental factors [30]-[35].

2.2. The MIL-HDBK-217

The MIL-HDBK-217 is the military handbook for the reliability prediction of electric and electronic equipment. It was developed in 1961 and has been frequently updated, with the most recent update in 1995 (see Table 2). The purpose of MIL-HDBK-217 is to establish consistent and uniform methods for estimating the *inherent* reliability of equipment and systems. By *inherent,* we mean the reliability of a mature and confident design [37]-[40].

MIL-HDBK-217 is a worldwide standard for performing reliability predictions. It includes a series of failure models based on empirical studies. These models virtually cover all electrical/electronic parts that are based on empirical studies. It also estimates 14 separate operational environments, such as ground fixed, airborne inhabited, etc. [41].

2.3. The reasons for success of the MIL-HDBK-217

The first handbook on reliability prediction, the 'Reliability Stress Analysis for Electronic Equipment' or TR-1100, was released by the Radio Corporation of America (RCA), one of the

Table 1. Overview of Reliability manuals.

Name	Application	Last Issue
MIL-HDBK-217	Mil/Commercial	1995
Bellcore / Telcordia	Telecom	2006
RDF 2000	Telecom	2000
SAE Rel. Pred. Meth.	Automotive	1987
NTT Procedure	Telecom	1985
Siemens SN29500	Siemens Prop.	1999
China 299B	Chinese Mil	1998
PRISM	Mil/Commercial	2000

most important manufacturers of electronic components (especially vacuum tubes).

The handbook presents some important mathematical models for estimating electronic component failure rates and was the predecessor of what would be become the standard and a mandatory requirement for reliability prediction in the decades to come, MIL-HDBK-217 [4].

The first mathematical approach used in MIL-HDBK-217 is to estimate the failure rate by fitting a line through the field failure data. Soon after its introduction, all reliability predictions were based on this handbook, and all other sources of failure rates, such as those from independent experiments, gradually disappeared. The failure to use these other sources (see Tab. 1) was due to a very important fact: MIL-HDBK-217 was usually cited as a contractual document, preventing contractors from using other models or handbooks. In this sense, MIL-HDBK-217 is strongly linked to the practical and active aspects of the industrial world and is part of the Industry 4.0 because the companies involved in the design and installation of efficient lamps managed by a remote control draw on the latest and most innovative technologies of the Internet of things (IoT) by means of a monitoring and/or control and feedback process fully integrated into the IoT itself.

2.4. Two prediction methods

In MIL-HDBK-217, there are two important prediction approaches: the Part Stress technique and the Parts Count technique. As the names imply, the Part Stress method requires knowledge of the stress levels of each component to determine their failure rates, while the Parts Count technique assumes average stress levels as a means of providing an early design estimate of the failure rates. Throughout this article, we use only this second method for the analysis [42].

In MIL-HDBK-217, reliability is usually expressed in failures in time (FiT): the number of failures that can be expected in one billion (10^9) device hours of operations.

Typical factors used in determining a part's failure rate include a temperature factor (π_T), power factor (π_P), power stress factor (π_S), quality factor (π_Q), and environmental factor (π_E) in addition to the base failure rate (λ_b) method [43]-[44]. For example, the failure rate model for a resistor is as follows:

$$\lambda_g = \lambda_b \cdot \pi_T \cdot \pi_P \cdot \pi_S \cdot \pi_Q \cdot \pi_E.$$ (3)

Ideally, the Parts Count technique is applied early in the design phase to determine that the predicted reliability is in the same 'ball park' as the reliability requirements. As more detailed design information becomes available, such as detailed circuit schematics, the predictions should be refined to reflect actual applied component stress levels [45].

This necessitates switching to the more detailed Part Stress reliability prediction methodology, which can result in significantly more labour hours for circuit analysis to compute the actual stress levels for each part application. In some cases, the Parts Count results are used as the final mean-time-between-failure (MTBF) estimator, despite that the results can be conservative because of the default stress levels assumed in the methodology. This situation sometimes leads to an excess of spare components [46].

In our analysis, we use the Parts Count method. It gives more conservative results than the Part Stress method, and it assumes the typical operating conditions of part complexity, environmental temperature, general electrical conditions, and operation conditions (called reference conditions).

The failure rate is calculated according to the Parts Count method,

$$\lambda_{TOT} = \sum_{i=1}^{n} N_i \cdot (\lambda_g \cdot \pi_Q)_i \,, \qquad (4)$$

where:

λ_g is the failure rate of the generic part under environmental conditions
N_i is the quantity of the part i^{th}
π_Q is the quality factor
i is the number of part

As explained above, the MIL-HDBK-217 Parts Count method provides physically inconsistent data, so it is necessary to overcome the traditional approach to reliability analysis based on the failure rate or hazard rate, which is currently mature and has been consolidated in the international technical literature [47]-[53]. As mentioned, due to the extremely conservative feature of the Parts Count method, we have added the π_{cf} corrective factor, so the final version of Equation (4) is now

$$\lambda_{TOT} = \sum_{i=1}^{n} N_i \cdot (\lambda_g \cdot \pi_Q \cdot \pi_{cf})_i \,. \qquad (5)$$

2.5. COTS part and quality

The quality factor and the corrective factor are critical for establishing the reliability of the system. *Smart Street* is composed entirely of commercial off-the-shelf (COTS) electronic components. The approach to establishing the quality of the component cannot therefore be the canonical one of MIL-HDBK-217 and therefore requires other considerations about the evolution of the failure and the environment [54].

The term 'COTS part' or 'component' is defined by the Society of Automotive Engineers (SAE) as 'An electronic component developed by a supplier for multiple customers, whose design and configuration are controlled by the supplier's or an industry specification.'

The use of COTS parts needs a special technical approach due to a lack of confidence in traceability, long-term performance, and new concerns affecting such parts, including compliance, counterfeiting, etc. [55].

A complete reliability analysis of these parts that properly evaluates risk and countermeasures is dependent on sufficient technological knowledge from prior usage, lessons learned, datasheets, modelling techniques, and manufacturer's information [56].
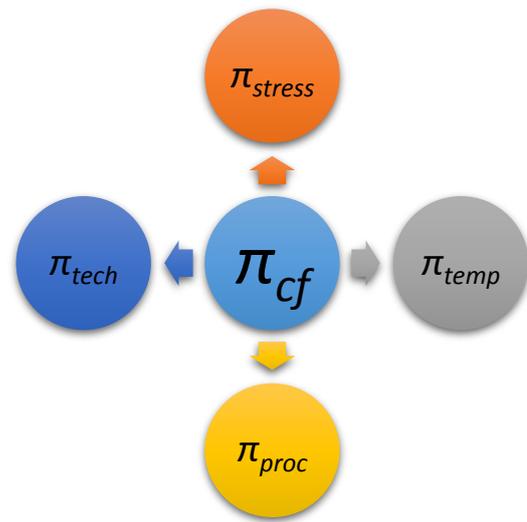
Figure 2. Corrective factor π_{cf} composition.

Specific studies should be made to evaluate the quality factor, with the primary concerns being:

– Part lifecycle and obsolescence monitoring, particularly for standard product lines;
– Use of historical performance data, long-term performance, and repeatable results;
– Lessons learned concerning a particular part type, part number, or manufacturer;
– The part's specific temperature constraints;
– Lot homogeneity;
– Procurement technique i.e. a controlled manufacturer's specification; and
– Counterfeit avoidance.

2.6. The corrective factor π_{cf}

The π_{cf} takes into account several parameters, including the technological factor, procedural factor, stress factor, and temperature factor [57] (see Figure 2). The complete expression is

$$\pi_{cf} = \pi_{tech} \cdot \pi_{proc} \cdot \pi_{temp} \cdot \pi_{stress} \,. \qquad (6)$$

In specific detail, we have:

π_{tech} - Technological Factor: MIL-HDBK-217 has so far remained behind regarding the technological capabilities of the individual electronic components since at the time of the last issue, it did not even imagine the rapid development of many manufacturing techniques and circuit integrations [58].

π_{proc} - Procedural Factor: The general philosophy of the handbook is to examine 'all the possible types of electronic components in all possible conditions in all imaginable environments' [59]. For this reason, MIL-HDBK-217 is highly rigid and schematic. In other words, to work well, the method needs to 'freeze' or rather to give a picture of the current electronic technology [60]; to study all the details; and then, after careful evaluation and testing, to deliver the reliability calculation algorithm.

$\pi_{temp} \cdot \pi_{stress}$ - Stress and Temperature Factor: In its broadest sense, to define the electric and thermal stress of the component, the environment (and other local stress) in which it is placed is not sufficient to establish its reliability.

Moreover, it is important the type and the components from which, the part in question is surrounded.

The π_{tech} technological factor is composed of three other factors,

$$\pi_{tech} = F_{complex} + F_{confidence} + F_{homog} \, , \qquad (7)$$

where:

$F_{complex}$ – Complexity Factor: This parameter takes into account the class of the technological complexity of the component or subsystem.

$F_{confidence}$ – Confidence Factor: This parameter takes into account the duration of the production period of the component or subsystem and its length of service.

F_{homog} – Homogeneity Factor: This parameter takes into account the differences in production and the level of difference between the different production lots.

The π_{proc} procedural factor is composed of three other factors,

$$\pi_{proc} = F_{hum} + F_{manufact} \, , \qquad (8)$$

where:

F_{hum} – Human Factor: This parameter takes into account any human-caused errors or imperfections of assembly.

$F_{manufact}$ – Manufacturer Factor: This parameter takes into account any errors or imperfections due to secondary processing techniques.

The π_{proc} temperature factor is expressed as:

$$\pi_{temp} = \int_{T_0}^{T_t} f_{T_{degr}} (T)dT \, . \qquad (9)$$

The function $f_{T_{degr}}$ expresses the degradation mode of the component or the subsystem that evolves from the temperature T_0 up to the final temperature T_t, recording the trend and all the possible variations.

The π_{stress} stress factor is expressed as:

$$\pi_{stress} = \int_{t_0}^{t} f_{Stress} (t)dt \, . \qquad (10)$$

The function $f_{T_{degr}}$ expresses the way in which the component or the subsystem is stressed or how much and how its operation moves from the ideal mode and approaches its critical limit [62].

The total corrective factor is now expressed as:

$$\pi_{cf} = \left(F_{complex} + F_{confidence} + F_{homog} \right)$$
$$\cdot \left(F_{hum} + F_{manufact} \right)$$
$$\cdot \left[\int_{T_0}^{T_t} f_{T_{degr}} (T)dT \right]$$
$$\cdot \left[\int_{t_0}^{t} f_{Stress} (t)dt \right] . \qquad (11)$$

Note that some elements of the function are not linear and in any case are not related to each other over time [63].

From a physical point of view, we can see the mathematical function as if many degradation processes act on the various components of the system in a completely independent way [64].

2.7. Uncertainty and component degradation

In this section, starting from the component degradation model, we define the limits and uncertainty criteria for determining the optimal value that meets or exceeds the maximum life threshold (expected life). We evaluate the level of degradation for the ith specimen for a time $\hat{t} \in [0, \infty)$ in a cycle of single use $\Psi_i = \{\psi_{i,1}, \dots, \psi_{i,Q}\}$, $Q \in \mathbb{N}$, then a set of random specimen variables $\Omega_i = \{\omega_{i,1}, \dots, \omega i, v\}$, $V \in \mathbb{N}$ that defines the *health* (degradation status) of the part, following a normal (Laplace–Gauss) distribution.

Now, we define the expected useful life (reliability) as the probability that the degradation at time T_η reaches the theoretical failure threshold η before time $\hat{t}$ is:

$$P_r\{T_\eta < \hat{t}\} = P_r\{H(\hat{t}; \Psi_i, \Omega_i) > \eta\}, \qquad \forall i \in I . \qquad (12)$$

We consider a component with the following degradation path (which has been chosen because it is typical of such components):

$$H_i (t, \Psi_i, \Omega_i) = \psi_{i,1} + \omega_{i,1} \cdot \hat{t}^{\psi_{i,2}} \, , \qquad (13)$$

where $\Psi_i = \{\psi_{i,1}, \psi_{i,2}\}$ and $\Omega_i = \{\omega_{i,1}\}$, then:

$$P_r\{T_\eta < \hat{t}\} = P_r\{\psi_{i,1} + \omega_{i,1} \cdot \hat{t}^{\psi_{i,2}} > \eta\} \qquad (14)$$

$$P_r\{T_\eta < \hat{t}\} = P_r\left\{\omega_{i,1} > \frac{\chi - \psi_{i,1}}{\hat{t}^{\psi_{i,2}}}\right\} . \qquad (15)$$

For a random specimen health variable, $\omega_{i,1} \geq 0$, we evaluate the cumulative density function $F_{\omega_{i,1}}$:

$$P_r\{T_\eta < \hat{t}\} = 1 - F_{\omega_{i,1}}\left(\frac{\eta - \psi_{i,1}}{\hat{t}^{\psi_{i,2}}}\right) . \qquad (16)$$

We define the control time points as a time interval in which the performances of the component are checked (tested). Obviously, the component cannot be monitored continuously throughout the degradation process. Rather, it is checked at regular intervals.

Now, we evaluate the probability according to which, between the two control time points $(n - 1)\tau$ and $n\tau$, the expected life E_L is reached:

$$P_r\{H_i((n - 1)\tau; \Psi_i, \Omega_i)\} \leq E_L < H_i(n\tau; \Psi_i, \Omega_i), \quad \forall n \in \mathbb{N} . \qquad (17)$$

So we define T_{E_L} as:

$$P_r\{(n - 1)\tau) \leq T_{E_L} < n\tau, \qquad \forall n \in \mathbb{N} . \qquad (18)$$

The real failure threshold H_i is reached before time point $n\tau$ only if it has satisfied the following condition:

$$P_r\{H_i(n\tau; \Psi_i, \Omega_i) > \eta_i\} = P_r\{T_{H_i} < n\tau\}, \quad i \in I . \qquad (19)$$

Moreover, assuming the degradation path is monotonic (typical of this kind complex systems), we have $E_L < H_i$ and $T_{E_L} \leq T_H$.

The probability that a failure happens at the specific time $n\tau$ after the degradation level of the ith component has reached the failure limit $(n - 1) \cdot \tau \leq E_L < n\tau$ is:

Table 2. Reliability analysis summary (baseline).

Description	λ_P in F/(10^6 hrs)	σ	Q.ty	λ_P TOT in F/(10^6 hrs)	MTBF in hrs
Ethernet (Multiswitch side)	0.08	0.05728	1	0.08	12 048 192.8
Media converter (Multiswitch side)	4.78	0.01047	1	4.78	209 205.0
Telephone Cable	0.07	0.00788	1	0.07	15 384 615.4
Media converter (Hub side)	4.78	0.34634	1	4.78	209 205.0
Ethernet (Hub side)	0.08	0.06739	1	0.08	12 048 192.8
Hub	11.60	0.00911	1	11.60	86 206.9
Camera	232.55	0.00084	1	232.55	4 300.2
IP NX8390	5.41	0.01278	5	27.05	36 968.6
LED Driver LE414	108.75	0.56069	5	543.77	1 839.0
LED Lamp	57.00	0.08015	5	285.00	3 508.8
Total Reliability: λ_{TOT} in F/(10^6 hrs)				1109,77	
(equivalent to) MTBF (R_{Total}) in hrs				901,09	

Table 3. The *Smart Street* system: 'Level 1' criticalities (FMECA extract).

N°	Item/ Sub-Item	Failure Mode	Observable Symptoms	Prevention and Compensation Methods	Criticality	Recommendations and Comments
1.1.4	Concentrator	Major Failure (Short Circuit)	Offline concentrator and electricity line safety devices engaged. Impossible to access individual nodes.	None	1	The failure could also spread on the line to other units.
1.2.2	Concentrator	Major Failure (Short Circuit)	Concentrator off. The fault also propagates to the other parts of the concentrator. Power line safety devices engaged. Impossible to access individual nodes.	None	1	The failure could also spread on the line to other units.

$$P_r\{PM \ at \ n\tau\} = P_r\{T_{H_i} > n\tau, (n-1)\tau \leq T_{E_L} < n\tau\}. \quad (20)$$

So, we define the uncertainty in the reliability assessment of the component U_λ as:

$$U_\lambda = H_i - E_L. \quad (21)$$

2.8. The baseline reliability analysis

The baseline pilot system is presented in detail in Table 2. It consists of five street lamps (each complete with LED arrays, drivers, and an IP node), one of which is equipped with a camera [65]-[71]. Information on the health status of the street lamp, its consumption, and the camera data are sent to a hub, then the information is converted for transmission in the telephone network through two media converters. In the end, the information are sent to a multiswitch that sends them to users who request them [72]-[73]. The failure analysis of the baseline system returned a MTBF$_{TOT}$ equal to 5,483 hours, which is equivalent to about 20 months of operation (with the lamps being active 10 hours per day) [74].

The most critical component is the LED driver, which alone gives around 50% of all FiTs of the system. It is the part that is most prone to failure and therefore the most likely candidate for an appropriate stock escort [75].

The analysis resulted in a value of MTBF$_{CAMERA}$ equal to 4,300 hours, equivalent to about six months of uninterrupted operation. This seemingly low value is due to the fact that the camera is still prototypal, and updates, both software and hardware, are constantly made to it.

A critical component is certainly the hub which, in the face of a comforting MTBF$_{HUB}$ of 86,200 hours and in the case of catastrophic failure, should cause complete shutdown to all the sections of the lamp network [76]-[81].

3. FMECA: METHOD AND RESULTS

3.1. Criteria

The FMECA is a methodology designed to identify the potential failure modes for a product or process, to assess the risks associated with those failure modes, to rank the issues in terms of importance, and to identify and carry out corrective actions to address the most serious concerns [82].

In the FMECA, the entire system is examined on a functional level, and the effects of failures and malfunctions on the performance of the equipment are determined. The interface circuits of the various subsystems, on the other hand, are analysed at the component level [83].

For each failure mode, the effect, cause, and ways of remedying the failure are studied, with particular attention to any recommendations for changing the project or prevention methods and the frequency at which the failure mode is observed (if possible) [84]-[88].

These results are used for identifying 'singular' faults (single point failure [SPF]), critical elements, errors, and underestimations of the project and for checking, as far as possible, that all critical failure modes can be fully tested at the subsystem level during assembly [89]-[91]. In Table 3, we can see an extract of the FMECA tables. We have selected all the occurrences of Grade 1 faults (the most serious), i.e. those in which the failure of one system (or unit) can spread to other systems (or adjacent units). The table, for the sake of brevity, does not show all the columns of the FMECA. Rather, only the most interesting and coherent ones are presented.

3.2. FMECA assumptions

In the subsequent FMECA, the following presumptions are made:

- The total failure of the examined function is presumed;
- Only one failure mode is considered at a time (i.e. no correlated failures are taken into consideration, except as recommendations);
- The FMECA is performed at the function and unit levels, with the exception of interfaces that are analysed at the component level (wherever possible and opportune); and
- The probability of failure, which is the subject of a specific analysis, is not considered.

3.3. Results

The presumed failure mode reported in the FMECA tables is reported as a function of the worst fault i.e. the loss of the function of the main unit [92].

The *Smart Street* system has been examined in the form of a pilot system with a number of LED lamps reduced to five, one of which is equipped with a video camera. A possible increase or decrease in the number of the lamps without a camera does not significantly affect the philosophy of the approach to the reliability study of the overall system [93].

Note that, despite no part of the system is redundant, the system is quite resilient and not "damage sensitive". In fact, not

Table 4. Configurations trade-offs.

| # of LED Lamps | MTBF in hrs | | Δ_{MTBF} | Δ_{MTBF} in % |
	Single Hub	Multi-Hub		
5	901.1	901.1	0.0000	0.0000
10	452.5	454.9	2.3882	0.0053
15	302.1	304.3	2.1329	0.0071
20	226.8	228.6	1.8039	0.0080
25	181.5	183.0	1.5415	0.0085
50	90.8	91.7	0.8696	0.0096
100	45.4	45.9	0.4596	0.0101
150	30.3	30.6	0.3119	0.0103
200	22.7	23.0	0.2360	0.0104
250	18.2	18.4	0.1898	0.0104
500	9.1	9.2	0.0959	0.0105
1000	4.5	4.6	0.0482	0.0106
1500	3.0	3.1	0.0322	0.0106
2000	2.3	2.3	0.0242	0.0106
2500	1.8	1.8	0.0193	0.0106
5000	0.9	0.9	0.0097	0.0106

Figure 3. Number of LED lamps vs. Δ_{MTBF} [%].

only can it withstand the lowering of light intensity, but the loss of operation of more than one LED, strip, or even a whole streetlight is borne without reaching a minimum brightness that would prevent a correct view of the road [94].

For the avoidance of doubt, although all streetlight systems are strictly the same (except the one with the camera) and have all the same functions, the system cannot be considered as a parallel reliability system [95]-[97].

4. SCALABILITY OF THE SYSTEM

Scalability is the capability of a system or network to handle a growing amount of work or its potential to be enlarged to accommodate that growth [98].

Our system is a classic case of a system that lends itself very well to scalability. Now, we examine the strategies necessary to perform the scale-up of the system. We estimate that up to 5,000 street lamps are needed for a small city [99]. The two configurations that we will be using in the trade-off (Table 4) are quite different. In the first case, we use a single hub to connect all the groups 'IPNX8390 + LED Driver + LED Lamp' and to manage the single street lamp. In the second case, we use one hub for every five groups of street lamps. In both of the configurations, we observe how the reliability varies with the increase in the scale in terms of the number of streetlights [100]. The first line gives us the number of lamps considered in the scale-up; and the second and third return the MTBF value of the two configurations under consideration.

The last two columns illustrate the Δ_{MTBF} between the first single-hub and multi-hub configurations in both absolute and percentage terms.

We can immediately see that after 100 lamps (Figure 3), the Δ_{MTBF} factor varies very little, so the reliability of the two architectures seems to be equal. This is a consideration that is incorrect in substance.

Note that after 200 lamps, the difference between the two systems remains absolutely negligible before significant changes.

From a FMECA point of view, you can see that all the lamps in the first configuration depend on only a single hub [101]. Even if the simple evaluation of the Parts Count method tells us the opposite, we immediately note that the availability of the system
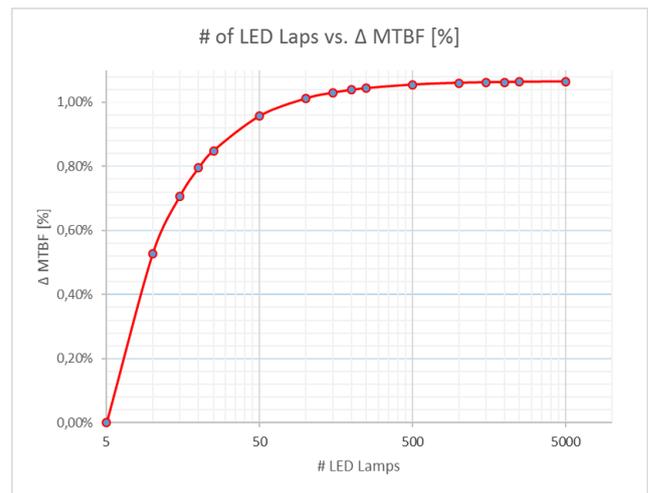
is seriously compromised because a hub fail causes the switch off all the lamps. In the second configuration instead, we would have a much more modest loss of the only group of five lamps [102].

This is evidenced by the fact that the hub of the first configuration is a 'single point failure' of a critical type, which therefore entails the disastrous loss of all the functionality of the system.

5. CONCLUSIONS

The combination of a reliability analysis and FMECA has allowed us to manage the scale-up of the systems without needing to choose apparently reliable configurations that instead prove to be extremely vulnerable from the point of view of operational availability.

The reliability analysis was performed using the Parts Count analysis of the MIL-HDBK-217, appropriately modified to take into account several parameters (including the technological, procedural, stress, and temperature factors), in order to obtain the most realistic results for the study of the COTS components of the *Smart Street* system.

The FMECA helped us to identify the 'single point failure' of a configuration that proved to be suitable. In any case, one cannot ignore the "reliability analysis" in identifying the weakest and most vulnerable points. In our study, the FMECA pointed out which parts of our system need to do more stock, regardless of its reliability value.

The study of the scalability of the system shows that some critical parts (i.e. the hub) impose a 'single point failure' that could affect the functionality of the system itself. Even at the cost of raising the figure of overall reliability, it is necessary to multiply these parts in order to remove this point of singularity.

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