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Master Thesis Title:

Risk analysis on a car-sharing project of an electric microcar through application of PM best practices and preliminary failure analysis

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Abstract

Can electric microcars enter the world of car sharing? What are the risks associated with this project?

These are the questions answered in this experimental thesis, which proposes a model in which both project activities and individual process activities are analysed. Starting with an initial risk identification phase, the analysis goes on with a qualitative analysis to prioritise the risks identified.

This is followed by the preliminary RAMS analysis, in which the criticalities associated with the failure of each component are examined.

In the last step, there are the conclusions based on the results obtained, and the description of the strategies to apply.

Contents

Introduction

The aim of this thesis is to apply preliminary RAMS and Project Risk Management techniques to a real case study. It is presented the possible failures, maintenance and safety related to accidental situations of the battery pack of an electric microcar. In addition, it is introduced a Risk management analysis of the battery swap process made at service stations. The carsharing project of the car starts from the engineering phase to the commissioning stage. The project is broken down into basic activities which are analysed individually to assess which strategies might be proposed.

In the first chapter, the main objective is to provide a general overview of what is Risk Management and how it is approached with respect to electric microcars. After providing an overview, the dissertation goes into detail by analysing the preliminary RAMS techniques used in the study of battery pack limits such as a standard FMECA (Failure Mode, Effect and Criticality Analysis). Risk Management concepts used in the identification and prioritization of Process and Project risks are presented, such as: Ishikawa Diagram, SWOT Analysis, WBS (Work Breakdown Structure), RBS (Risk Breakdown Structure) and RBM (Risk Breakdown Matrix).

In the second chapter there is the presentation of the methodological research conducted, where the analysis techniques explained in the previous chapter are applied to real case in examination. The first part of the chapter deals with the aspect of Project Management applied to a car sharing project in the city of Turin. The second part of the chapter is an exploratory part, where the physical and functional limits of the battery pack are studied from an engineering point of view, through a FMECA analysis and a Reliability Block Diagram.

In the third chapter, the results obtained from the identification and prioritization of the Project risks are highlighted through bar graphs and donut charts, to understand the relevance of risks in the Project. In addition, there is the evaluation of the results obtained from the preliminary RAMS analysis to understand how much the failures can affect the SWAP service.

In the fourth chapter are drawn the conclusions on the RAMS and Risk Management analyses, proposing a strategy for Project and Process risks, which can be: accepted, avoided, transferred, or mitigated.

Chapter 1 - Analysis of literature

In this chapter are provided the basic knowledges about the Risk Management techniques used to identify and prioritize risks before their occurrence; therefore, there is the planification of some oriented actions to manage them.

1.1 Principles of Risk Management

The processes that compose a project, from the initial stages to the commissioning final phase, deal with a certain level of uncertainty. For this reason, every project must deserve a particular attention about risk management. The most important principle of this field is the dynamicity of the risk state since a risk can change its status as time goes on. The behaviour of risk management approach in companies develops and advances in coexistence with strategy and governance attitudes. The status of portfolios, programmes and projects is likely to change frequently. In fact, continuous adjustments become necessary as the organisation grow up.

Most of the time, there is a specific need for an effective and efficient identification of risks that directly affect the aims and objectives of the organisation. The key challenge for many companies is to obtain the optimal management of the available resources by focusing on the right risks. Therefore, it is important to clarify the goals, requirements, and scope of initiatives, to facilitate the identification of risks and enhance the possibility to manage them in a clever way.

For a firm, the greater is the use of risk management techniques to address critical issues, the higher the performance in terms of efficiency and business results. It is also fundamental to maintain a good propension to the continuous improvement of risk management skills, to create a sustainable competitive advantage to the detriment of competitors in the market.

1.2 Definition of key-concepts

Each company in the market must deal with uncertainty of events that can be external or internal respect to the organization. The uncertainty related to a risk can be viewed as a threat or as an opportunity, in fact it is crucial for the firm to address them reaching the prefixed goals through specific strategies.
In the following lines are described the main concepts to apply Risk Management to these uncertain events.

"An individual risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more objectives. Overall risk is the effect of uncertainty that affects organizational objectives at different level or aspects"[1].

A certain risk has two fundamental dimensions:

- Likelihood;
- Impact.

The likelihood is intended as the probability that a specific uncertain event can occur, instead the impact is depicted as the effect on project's objectives if the risk occur.

Let P as the probability and I as the impact, it is common to define a measure of the risk R as:

$$R = P * I$$

Empirical studies show that in risk perception the importance given to impact is far greater than that given to probability[2], in fact the above equation can also be interpreted as:

$$R = I^k * P \quad \text{with } k > 1$$

There may also be complex systems, where n events are associated with each risk to take into account all the risks that may exist, as shown below:

[1] Project Management Institute Inc., "The standard for Risk Management in Portfolios, Programs and Projects", 2021, Global Standard, Newton Square, Pennsylvania, USA, page 7.
[2] Enrico Zio, "Series on Quality, Reliability and Engineering Statistics – Vol. 13, An Introduction to the basis of the reliability and risk analysis", 2007, World Scientific Publishing Co. Pte. Ltd., Singapore, page 9.

$$\sum_{i=1}^{n} P_i * I_i$$

Assessing the risks by distinguishing between two components is essential. You might have two equal risk values and think they have the same characteristics; instead, one might have a high impact with low probability, the other a negligible impact with high probability.

The individual risks can affect positively or negatively the goals, single tasks completion and elements of a project. The correct understanding of individual risks provides the possibility to allocate effort and resources efficiently reaching good chances to achieve successful KPI's in the project.

There are two types of risks in terms of effects:

- The opportunities are risks with positive effects on the pursuit of objectives, in fact a good management of opportunities gives a substantial contribution to detect ways in which the goal can be reached successfully;
- The threats are risks with negative effects on the pursuit of objectives. The threat management is used to deal with these risks and actuate a planned response when is appropriate.

Threats that occur are called issues, instead the opportunity that come on are named benefits.

Another essential element is the attitude to risk taken by individuals and groups that can be risk lovers or risk averse. This attitude is determined by the strength of public commitments made on project performance and the inclination of stakeholders to take risks.

The risk threshold is a metric of the tolerable variation around a target, which reflects the organisation's risk appetite. Examples of risk thresholds are:

- minimum level of risk exposition for a given risk to be accounted in the risk register;
- maximum level of risk exposure which can be handled before escalation is initiated.

1.3 Risk Management in organizations

Risk management in the company is used to avoid issues and to reach the benefits sought by the company's strategies. Moreover, risk management helps to ensure that certain results are achieved within the constraints of the business.

Governance organisations are concerned to understand which risk management process is better for the business context and strategies. These decisions about which risk management processes to choose are left to executive management, since the achievement of certain strategic aims and the use of a certain process are strongly related.

The definition of risk includes both an event affected by uncertainty that can be clearly described, as well as a more general condition that may still give rise to uncertainty.

It is important to separate the concept of risk from the concepts associated with it. For example, the concepts of cause and effect have a well-defined function in their identification.

Causes are events that already exist or will certainly exist in the future, which may lead to a risk. Effects are hypothetical events which, if the risk occurs, will affect the strategic objectives of the firm.

1.4 Fields of Risk Management

Risk Management influences strategic decisions at various levels: enterprise, portfolio, programme, and project.

At the enterprise level, all strategic decisions have the goal to limit threats and maximise opportunities. The Enterprise Risk Management (ERM) of a company reflects the culture and the way in which corporate value is created and sustained. This method is different for each company and supports PDCA[3] (Plan, Do, Check, Act) to continuously enhance quality of business processes. ERM can vary from year to year, depending on the surrounding environment and the risk aversion of the stakeholders. It is important to make sure that between portfolio, programme and project management, there is a coherent alignment with the ERM used by the company.

[3] The PDCA or Deming cycle is an iterative process used for the continuous improvement of management cycles, through the activities of: Plan, Do, Check and Act, in https://www.insic.it/tutela-ambientale/plan-do-check-act-cose-il-ciclo-di-deming-e-come-funziona/

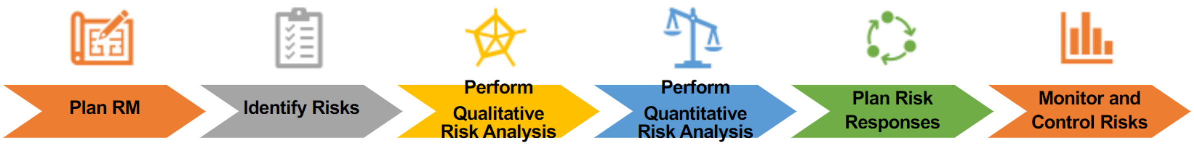
Within portfolio risk management there are three types of risks: structural, component, and overall risk. Structural risks are related to risks in the composition of projects and their interdependencies. The component risks at portfolio level are the risks that are taken to a higher level by managers to gain more information and action. The overall portfolio risk considers the sum of all individual component risks and their correlations.

Portfolio Risk Management is particularly important to conduct an optimal portfolio management, where value is lost on the failure of a single component and where the risk on one component impacts the risk of other components within the portfolio.

The Program Risk Management strategy, deals with defining the program risk thresholds, initialising the risk assessment, and developing the appropriate response strategy. The risk strategy at this level requires that the risk thresholds consider the organisational strategy and the risk attitude. Program risk management combines all operational risks for projects and component activities.

1.4.1 Risk Management in Projects

Project Risk Management has a life cycle starting from the planning of the risk plan to the monitoring and control of the risks.



[4]

Figure 1 Project Risk Management processes

In risk management planning it is ensured that the risk management plan is well integrated with the individual activities that make up the project itself.

Risk identification is the process of deriving a list of risks, which at the project level are based on operational and contextual inputs, defined by PMI and listed below.

The operational inputs are[5]:

[4] Alberto De Marco, "Risk Management, Identification, Analysis and Response", 2021, Turin, page 17

[5] Project Management Institute Inc., "The standard for Risk Management in Portfolios, Programs and Projects", 2021, Global Standard, Newton Square, Pennsylvania, USA, page 58.

- Project scope statement**:** Risks associated to the methods of delivery for products, services, or other results that are expected to be delivered by the project;
- Project life cycle: The life cycle itself introduces several risks;
- Work breakdown structure (WBS), activity list: Risks connected with the breakdown of project work and caused by its execution;
- Estimates: Estimates are performed in terms of time, cost, effort, and resources. The desired accuracy of an estimate is the permissible level of risk for that estimate;
- Dependencies and sequence of work: The resulting interdependencies and work sequence are risk sources;
- Procurement plans: Outsourcing parts of the project scope may be a risk transfer action, but it may also create new risks;
- Change requests: Whenever a change is applied in a project, it may eliminate some risks but also initiate new ones;
- Historical data: Since previous experience, it is important to clearly identify systemic risks and automate their treatment.

Contextual risks arise from the consideration of environmental elements of the company and other strategic or organisational aspects that shape the project environment, such as[6]:

- Stakeholder analysis: Any key player can bring a range of opportunities to be exploited; however, if poorly managed, they can bring threats that need to be mitigated;
- Business case**:** The business case often involves a profitability factor or a positive return on investment that is subject to some level of uncertainty or risk. The capacity to reach and maintain benefits after project closure is part of the risk identification. Risks which affect the achievement of benefits can be confronted while the project is in progress;
- Program or portfolio governance-level success factors: These elements change over time and modify the priority level of the project under the programme or portfolio.

[6] Project Management Institute Inc., "The standard for Risk Management in Portfolios, Programs and Projects", 2021, Global Standard, Newton Square, Pennsylvania, USA, page 58.

- Enterprise environmental factors: Factors such as the strategy of the organisation, its corporate structure, the Dynamical business environment and the variability of its regulatory environment are risk elements that impact on project.

The next step is the qualitative analysis, where the risks found in the previous step are qualitatively assessed and prioritised on the basis of probability and impact.
In the qualitative analysis, the data are used to perform an assessment of the combined effects on the project outcome.
In the risk response planning phase, guidelines are outlined to implement strategies and act on each risk with the correct timing.
In the monitoring phase, the effects of the strategies planned in the previous step are viewed and adjustments are made with respect to the project's progress.
In this thesis, the steps of risk identification, qualitative analysis and possible risk reponses are analysed in depth.

1.5 Risk identification

The process of identifying risks is characterised by a strong dynamism and reiteration, because some risks are not immediately visible and emerge later in the course of the activities that make up the project. Risks may be determined using various techniques, therefore empirical cases and documents relating to analyses carried out on similar projects can also be taken into account. A risk owner must be identified for each risk, who will then be the responsible to implement the response strategy.
The basic technique for identifying risks is that of the cause-effect relationship. This analysis starts from a cause, understood as a trigger or condition that leads to an uncertainty (risk) relating to the cause, leading in turn to an effect on the project.

1.5.1 Ishikawa diagram

An important tool to identy risks is the Ishikawa Diagram or Fishbone Diagram, devised by Kaoru Ishikawa.

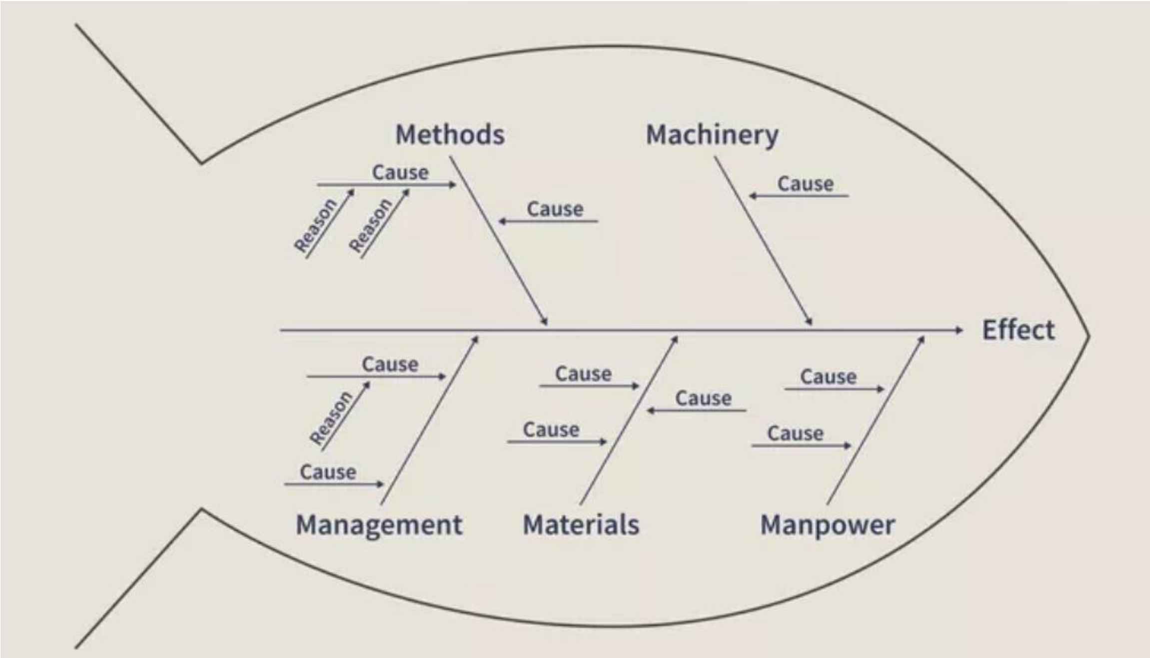


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Figure 2 Ishikawa Diagram

From the image above is possible to understand how this “skeleton of a fish” works. It has generic hierarchical headings (methods, machinery, management, etc.) and continues with "ribs" representing the causes leading to the effect, presented at the head of the skeleton. The task of this analysis is to present the problems related to a specific event or field underlying the related causes. In the case of this thesis project it is very useful to analyse some aspects of the service offered by the micro HV in the car-sharing environment.

1.5.2 Checklist

Checklists for risk identification are developed on the basis of data and information gained from the history of similar projects. It helps to divide the risks into categories and

[7] Julie Bang, Investopedia, 2020 in https://www.investopedia.com/terms/i/ishikawa-diagram.asp#:~:text=An%20Ishikawa%20diagram%20is%20a,are%20required%20at%20specific%20times

subcategories, in order to have a clear view of all the various fields that may affect the project.

1.5.3 SWOT Analysis

SWOT stands for: Strength, Weakness, Opportunity and Threat. SWOT is an analysis that applied to risks, allows to understand how they can be analysed against the 4 pivotal points of the SWOT. Strenghts and weaknesses are focused on internal factors, while Opportunities and Threats are more focused on external factors.

Each of these aspects allows elements to be listed by answering certain questions for each field.

Strengths What do you do well? What unique resources can you draw on? What do others see as your strengths?	**Weaknesses** What could you improve? Where do you have fewer resources than others? What are others likely to see as weaknesses?
Opportunities What opportunities are open to you? What trends could you take advantage of? How can you turn your strengths into opportunities?	**Threats** What threats could harm you? What is your competition doing? What threats do your weaknesses expose to you?

[8]

Figure 3 SWOT questions

1.5.4 Risk breakdown Structure

The RBS is a hierarchical structure used and approved by Risk Management standards. It is considered as the breakdown of the project carried out in the WBS [9], but for the risk field. The principal scopes for which this method is used are the following[10]:

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[8] https://www.mindtools.com/pages/article/newTMC_05.htm#:~:text=SWOT%20stands%20for%20Strengths%2C%20Weaknesses,four%20aspects%20of%20your%20business.&text=A%20SWOT%20analysis%20examines%20both,inside%20and%20outside%20your%20organization.

[9] The WBS is a hierarchical structure where the complexity of the project is broken down into basic activities, called work packages. Activities are categorised by function, area of competence or in other ways.

[10] Rafele, C., Hillson, D., & Grimaldi, S. (2005). Understanding project risk exposure using the two-dimensional risk breakdown matrix. Paper presented at PMI® Global Congress 2005—EMEA, Edinburgh, Scotland. Newtown Square, PA: Project Management Institute.

- Risk assessment: Risks that are discovered are tracked in the RBS and classified by their source. This shows the most significant sources of risk for the project, and indicates areas of interdependence or correlation between the risks;
- Comparison of alternatives: The risks related to competing bids and tenders are confrontable if the same RBS is used to structure their associated risks. This can also provide an input to understand how to manage trade-offs for alternative development options or investment decisions;
- Risk reporting: The risks are reported to different levels of stakeholders, to the project team to the senior management.

1.6 Qualitative Risk Analysis

"A qualitative risk analysis prioritizes the identified project risks using a pre-defined rating scale. Risks will be scored based on their probability or likelihood of occurring and the impact on project objectives should they occur."[11]

As reported by the table below, qualitative analysis is used to prioritise risks with respect to probability and impact. According to the Standards of the Project Management Institute, they are classified as follows:

SCALE	PROBABILITY	± IMPACT ON PROJECT OBJECTIVES		
		TIME	COST	QUALITY
VHI	61–99%	>40 days	>US$200K	Very significant impact on overall functionality
HI	41–60%	21–40 days	US$101K–US$200K	Significant impact on overall functionality
MED	21–40%	11–20 days	US$51K–US$100K	Some impact in key functional areas
LO	11–20%	6–10 days	US$11K–US$50K	Minor impact on overall functionality
VLO	1–10%	1–5 day	US$1K–US$10K	Minor impact on secondary functions
NIL	<1%	No change	No change	No change in functionality

[12]

Figure 4 Definitions for levels of Probability and Impact on Three Specific Objectives Used to Evaluate Individual Risks

[11] https://www.pmlearningsolutions.com/blog/qualitative-risk-analysis-vs-quantitative-risk-analysis-pmp-concept-1

[12] Project Management Institute Inc., "The standard for Risk Management in Portfolios, Programs and Projects", 2021, Global Standard, Newton Square, Pennsylvania, USA, page 136.

1.6.1 Probability and impact matrix

This type of matrix is fundamental to prioritize risks for further analysis and to provide responses. Thanks to this technicque is possible understand which risks influence more the project objectives in terms of likelihood and impact.

Risk Matrix						
	5 - Very High	VL, VH	L, VH	M, VH	H, VH	VH, VH
	4 - High	VL, H	L, H	M, H	H, H	VH, H
Probability Rating	3 - Moderate	VL, M	L, M	M, M	H, M	VH, M
	2 - Low	VL, L	L, L	M, L	H, L	VH, L
	1 - Very Low	VL, VL	L, VL	M, VL	H, VL	VH, VL
		1	2	3	4	5

Figure 5 Probability-Impact matrix

[13]

1.6.2 Risk Breakdown Matrix

The RBM is a two-dimensional matrix combining the WBS and the RBS, which are multi-level hierarchical structures. By forming this matrix it is possible to conduct a risk analysis for each work package in the project. In the cells of the matrix where there is a link between RBS and WBS, the risk is assessed by probability and impact. In this way the criticality of each work package can be assessed by adding up all the risks to which it is linked on its row, as expressed by the formula[14]:

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[13] https://www.researchgate.net/figure/Probability-impact-matrix_fig1_335181838

[14] Rafele, C., Hillson, D., & Grimaldi, S. (2005). Understanding project risk exposure using the two-dimensional risk breakdown matrix. Paper presented at PMI® Global Congress 2005—EMEA, Edinburgh, Scotland. Newtown Square, PA: Project Management Institute.

$$R_{WP,i} = \sum_{j=1}^{n} P_{i,j} * I_{i,j}$$

With:

- $R_{WP,i}$: total incidence of risks for the work package i;
- $P_{i,j}$: probability of risk j arising in the WP-i;
- $I_{i,j}$: impact of risk j in the WP-i.

A similar reasoning is applied to detect which risk has the greatest impact on the project, this is done by adding up the individual risks per column, represented in the following formula[15]:

$$R_{ris,i} = \sum_{i=1}^{m} P_{i,j} * I_{i,j}$$

With:

- $R_{ris,i}$: overall effect of risk source risk-j in the entire project;
- m : number of columns.

As a response different strategies can be implemented depending on the type of results and the firm environment. Follow three possible strategies:

- Attention can be focused on the single most significant risk with highest $R_{i,j}$, and continuing to the lowest one in decreasing order;
- The risk associated with the most critical element (work package) of the project, i.e. the maximum value $R_{WP,i}$. The risk response must focus on improving and making efficient the execution of that single work package;
- Considering the impact of the most relevant risk source on WPs, calculated on $R_{ris,i}$. In this case the strategy would be to reduce the presence of that particular risk source in the project.

[15] Rafele, C., Hillson, D., & Grimaldi, S. (2005). Understanding project risk exposure using the two-dimensional risk breakdown matrix. Paper presented at PMI® Global Congress 2005—EMEA, Edinburgh, Scotland. Newtown Square, PA: Project Management Institute.

1.7 Risk response strategies

After a clear identification and prioritization of the risks there are the responses application strategies that can be categorized as:

- Avoiding: The avoidance of the risks comport very strong strategic maneuvers based on the consideration of alternative solutions and the change of project objectives;
- Transferring: The risk transfer is a basic solution where the risk is transferred to stakeholders or a specific insurer, with the payment of a risk premium;
- Mitigating: The mitigation strategy include a set of possibile activities to reduce the overall risk value of the project. Some activities to take in consideration are the schedulation of the risky activities out the critical path, the resource allocation in order to minimize risk risk impact, and having frequent meetings to brainstorm on the critical risks and monitor them;[16]
- Accepting: The acceptance of the risk is taken in consideration when the impact and the probability risk is not relevant compared to the whole project, but it is fundamental to not forget these risks and to monitor them as the time goes on, in order to control the changes in their characteristics.

The following graphic represents the typology of strategies to apply on the basis of impact and probability.

[16] Alberto De Marco, "Project Management for Facility Constructions – A Guide for Engineers and Architects", 2011, Springer, Berlin, Heidelberg, page 179

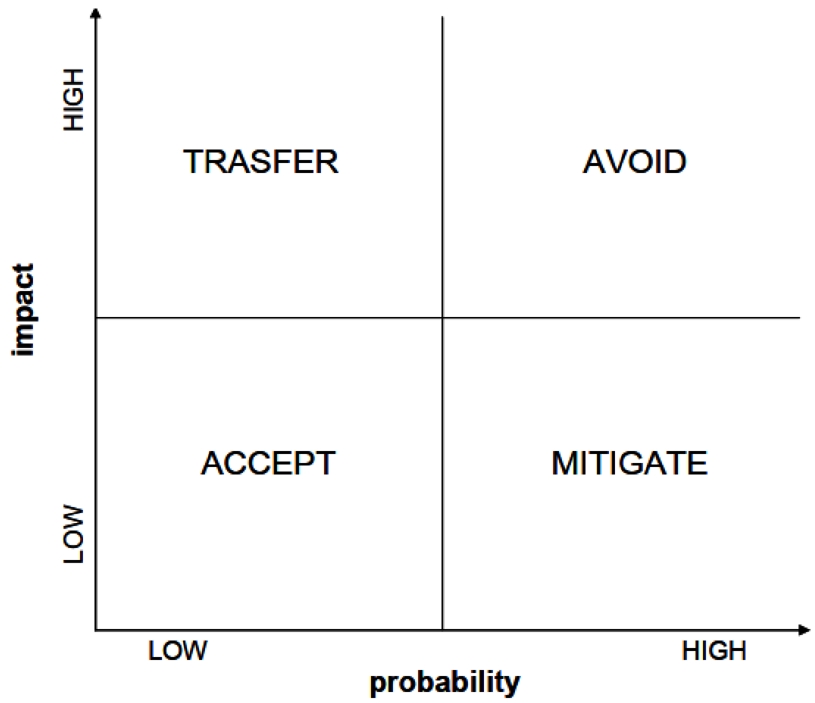

Figure 6 Main types of risk control strategies

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1.8 Methods for failure components identification

Risk can also be defined as the consequence of a hazard or damage.

One of the first steps in analysing a risk is to analyse it from the root, identifying the single hazards for which it may occur. Generally, this analysis is performed at the qualitative level using methodologies such as:

- Checklist
- Hazard index method
- Hierarchical trees
- System identification of release Points (SIRP)
- Failure Mode and Effect Analysis (FMEA)
- HAZard and Operability analysis (HAZOP)

The use of one of the methodologies listed above does not exclude the other. In this paper we will only give an overview of FMEA and its extension, FMECA. For more details

17 Alberto De Marco, "Project Management for Facility Constructions – A Guide for Engineers and Architects", 2011, Springer, Berlin, Heidelberg, page 178

please refer to the textbook “An introduction to the basics of reliability and risk analysis”[18].

1.8.1 FMEA and FMECA

The FMEA (Failure Mode and Effect Analysis) is an analysis that goes from the particular to the general, and is used to obtain an overall assessment of the availability of the product by analysing the failure rates. This method is aimed at identifying failure modes that may affect an entire system or lead to accidents. The first step is to break down the system under consideration into individual components and identify how they operate. For each line, it is important to include the failure modes and the effects that each failure may have on the system.

An update of the FMEA is the FMECA (Failure Mode, Effect and Criticality Analysis) where for each failure mode a criticality (severity) assessment is carried out: Negligible/Insignificant, Marginal, Critical and Catastrophic[19].

There is no standard procedure for carrying out FMECA, the following is an example of how such a table should be constituted.

Unique Ref.	Function	Operational Mode	Failure Mode	Effect	S	Failure Cause(s)	O	Detection System	D	RPN

Figure 7 Simplified FMECA worksheet

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The first column asks for a reference regarding the component being analysed, which may be an ID number or the name of the component.

[18] Enrico Zio, “Series on Quality, Reliability and Engineering Statistics – Vol. 13, An Introduction to the basis of the reliability and risk analysis”, 2007, World Scientific Publishing Co. Pte. Ltd., Singapore, page 11.
[19] https://en.wikipedia.org/wiki/Failure_mode,_effects,_and_criticality_analysis
[20] Domenico Maisano, “FMECA – Failure Modes, Effects & Criticality Analysis”, 2021, Turin, page 26.

In the second column the function or functions, if it has more than one, of the component is required.
In the third column, the operational mode where it is explained the state in which the component operates.
In the fourth column, failure modes are identified for each component function, understood as the failure to execute the functions in column two.
The fifth column lists the effects of the failure modes on the system.
In the sixth column the Severity is indicated, understood as the impact that the failure has on the system and on customer satisfaction.
The sixth column lists the causes for which failure modes occur.
The seventh column lists the occurrence, which is the frequency with which a failure cause occurs.
The eighth column lists the possible techniques to detect the failure cause.
In the ninth column there is the detectability index, which indicates on a scale from 1 to 10 the probability that the failure mode related to the failure cause is detected before the customer notices it (in this case a negative connotation is used for high values).
In the last column the RPN (Risk Priority Number) is calculated, which is given by the following formula:

$$RPN = S * O * D$$

This index has a negative correlation and has a specific meaning and evaluation for each different FMECA.
In the analysis provided in this elaborate the RPN index is not calculated, since the product (electric microcar) has been already manufactured.

1.8.2 Pareto chart

A Pareto chart is a bar graph. The lengths of the bars represent frequency or cost (time or money). They are arranged with the longest bars on the left and the shortest on the right. In this way the graph visually represents which situations are most significant. An example follows:

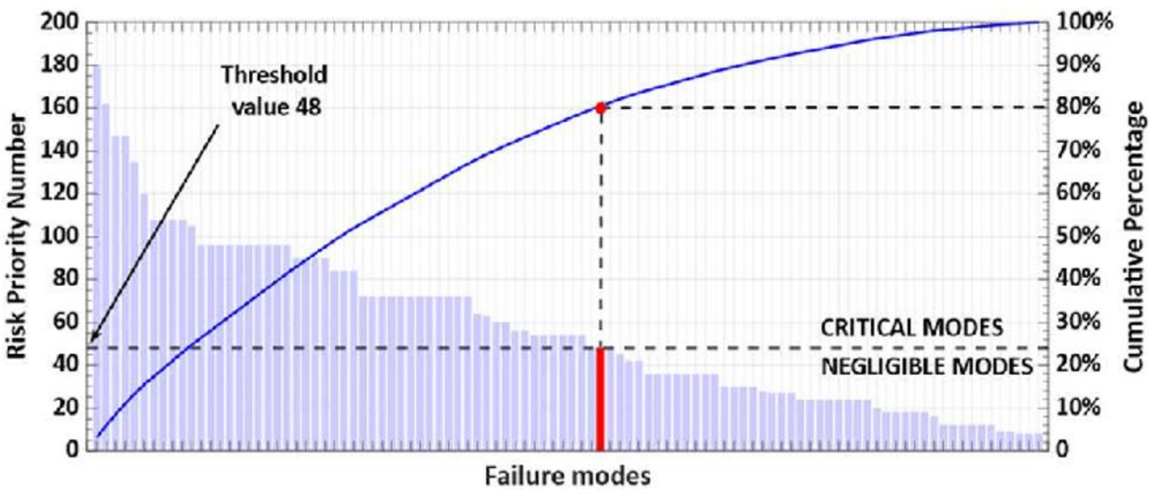

Figure 8 Example of Pareto Chart for Failure Modes

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The Pareto 80:20 rule is the most appropriate method for prioritising and classifying the failure modes of the most critical components. In fact, the Pareto analysis starts with the prioritisation (bar graph) of failure modes, placing them in decreasing order, from left to right. The bar graph is combined with a line graph indicating the cumulative RPNs in percentage terms, from highest to lowest failure.

The line graph is very helpful in understanding where the company needs to invest to minimise failures.

[21] https://www.researchgate.net/figure/Evaluation-of-RPN-threshold-using-Pareto-chart-and-8020-principle_fig5_338754721

Chapter 2 - Methodological research

The research part of this paper focuses on a risk analysis conducted from three different perspectives:

- The project on which the risk identification and prioritisation process is focused, is a car-sharing project. A manufacturer of electric vehicles wants to bring its microcars into the world of car sharing in Turin, to support Sustainable Urban Mobility, which has become a priority in the logistics of metropolitan cities;
- The battery swap process performed by a technician at the charging stations, whenever the customer has low batteries during a trip, or if he/she needs assistance;
- The battery pack is analysed in its individual components as a subsystem of the microcar system. It was chosen because it is the part affected during the process of battery swap.

2.1 Analysis of the project

The carsharing project was analysed regarding its risks using the Risk Breakdown Matrix. To do this, the risk management process started with a decomposition of the project by the WBS, then moved on to the identification of the risks with the appropriate identification methods. The latter led to the ramification of the Risk Breakdown Structure which, combined with the WBS, constitutes the model created for this specific project.

2.1.1 Work Breakdown Structure

In the first breakdown of the WBS the project is divided into six areas: Engineering, Agreements, Procurement, Building and civil works, Employees and Commissioning.

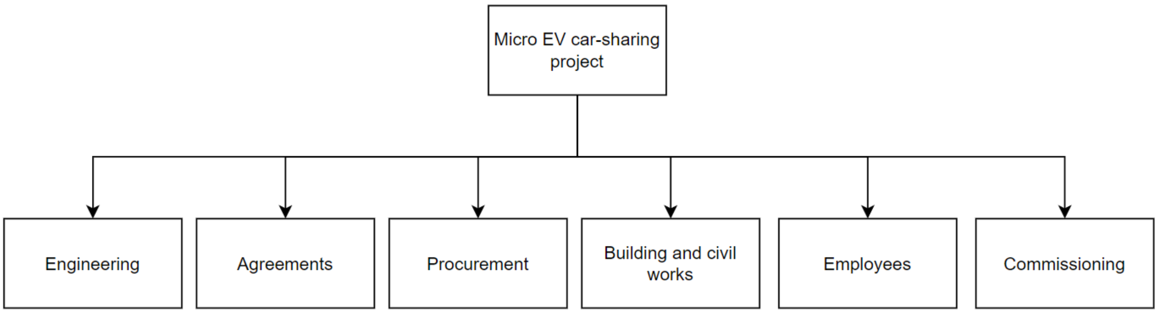


Figure 9 WBS first level – Phases

Each phase, in turn, branches out to form the most basic activities of the Work Breakdown Structure. As for the Engineering phase, it is understood as the phase in which the engineering of the charging stations needed for the car-sharing project is performed. It is divided into:

- **Basic Design**: a primitive design of how charging stations should be structured is provided;
- **Detailed Engineering**: the basic design carried out in the previous step is deepened and it is provided the final version of how the service stations should be built or modified;
- **Submission and approval of engineering set of drawings**: the detailed engineering output is sent and possibly approved by the competent authorities.

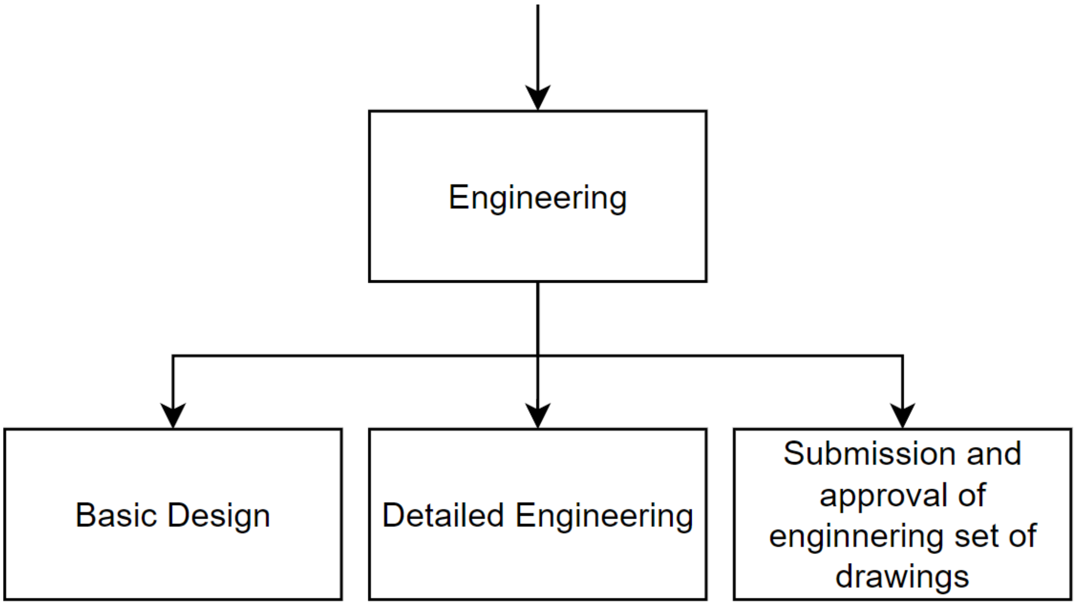


Figure 10 Engineering phase

The next phase is the Agreements phase, where all agreements between the entities influencing the carsharing project, both public and private, are defined. This phase is divided into two parts:

- **Partners' agreement**: Agreements are defined between the partner companies in the car-sharing project, including: the company producing the micro EVs that supplies the vehicles used for the project, the company responsible for building or modifying the infrastructure, and other minor partnerships;
- **Agreements with public entities**: Agreements and permits with public bodies are defined for the erection of new stations and the commissioning of car-sharing.

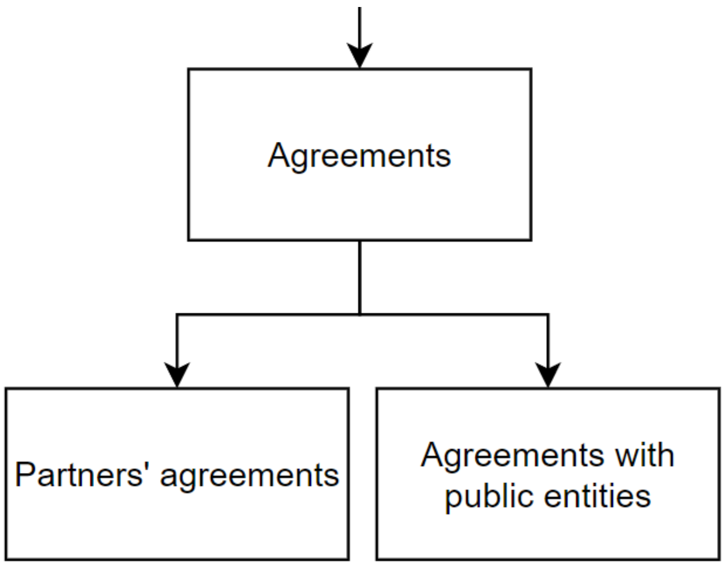


Figure 11 Agreement's phase

The third phase is procurement, which branches out into:

- **Procurement of the necessary material for the facility construction**: Negotiations are carried out to procure raw materials in order to erect charging stations or modify existing ones;
- **Procurement of the necessary EVs**: Car-sharing company procures the necessary number of electric microcars to start the project.

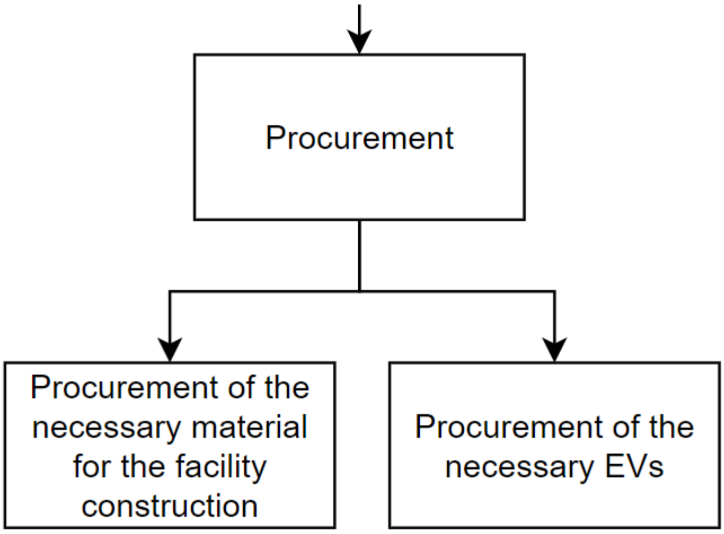


Figure 12 Procurement Phase

The following phase is focused on Building and civil works which is composed of:

- **Clearing sites for new stations**: The places where the new charging stations are to be erected must be cleared for the start of works;
- **Construction of charging station sites**: The construction phase is itself divided into
  - **Site preparation:** The location where the work is to be done is prepared;
  - **Foundations:** Foundations are built from where charging stations can be constructed;
  - **Station erection:** Charging stations are built.
- **Upgrade stations**: If there are charging stations (already in use) that can be adapted to the new battery swap service offered, work is carried out directly on the following stations.

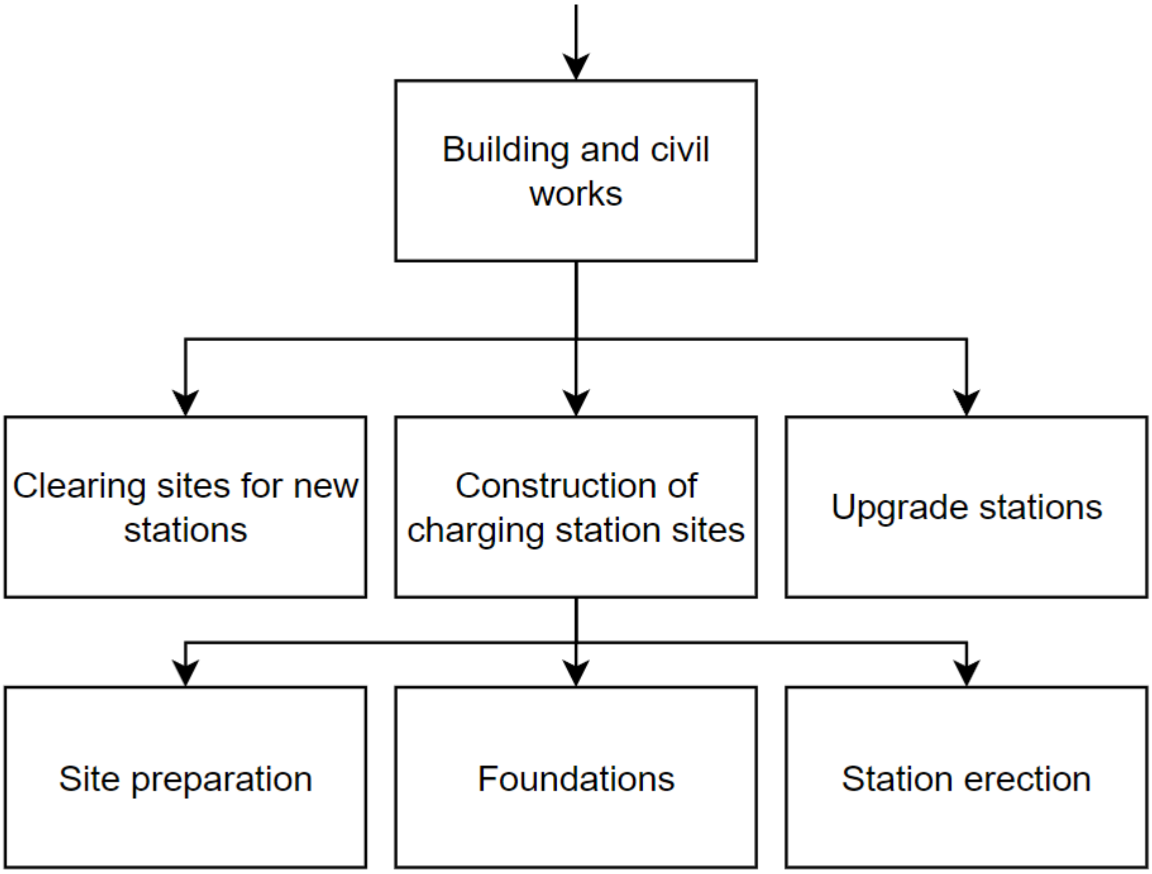


Figure 13 Building and civil works Phase

One of the crucial phases is the Employees' phase, where technical staff is recruited and trained on how the battery swap should be performed taking the appropriate precautions.

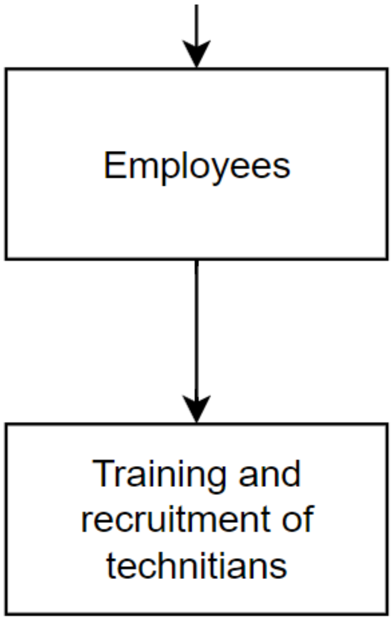


Figure 14 Employees Phase

The last phase is Commissioning, which represents the testing of the service and the launch on the market.

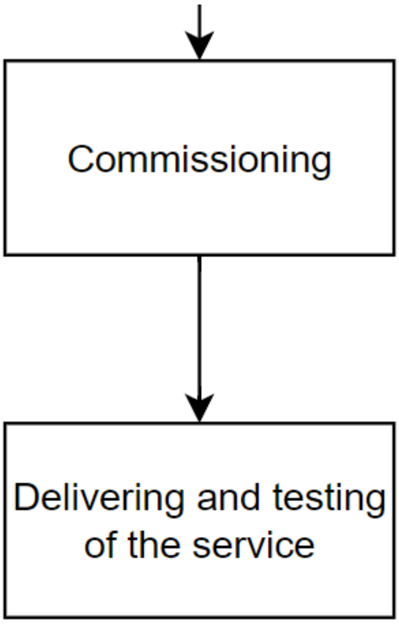


Figure 15 Commissioning Phase

These are all the components of the project, which is represented in its entirety as a WBS.

2.1.2 Risks identification

The identification of project risks is based on the techniques outlined in the Project Management Standards. The Risk Breakdown Structure is based on a checklist developed from historical information and from similar projects.

In the RBS six risk areas have been identified: Technical risk (TR), Project Management risk (PMR), Economic/Market risk (EMR), Commercial Risk (CR), Social/Environment risk (SER), External Risk (ER).

2.1.2.1 Ishikawa Diagram

The risk analysis was deepened with an Ishikawa Diagram where the safety of the micro EV is analysed, with the following hierarchical headings: Environment, Materials, Personnel, Driver.
The following analysis is based on a hybrid risk identification of project and process, in fact all the risks found in this type of analysis are explained, some risks being both process and project risks.
For the sake of simplicity, the risks directly linked to the causes, for which the safety of the electric vehicle is jeopardised, are shown below (unlike the classic fishbone diagram where only the causes are shown).
All the gills that make up the fishbone are analysed in the following branches:

Environment

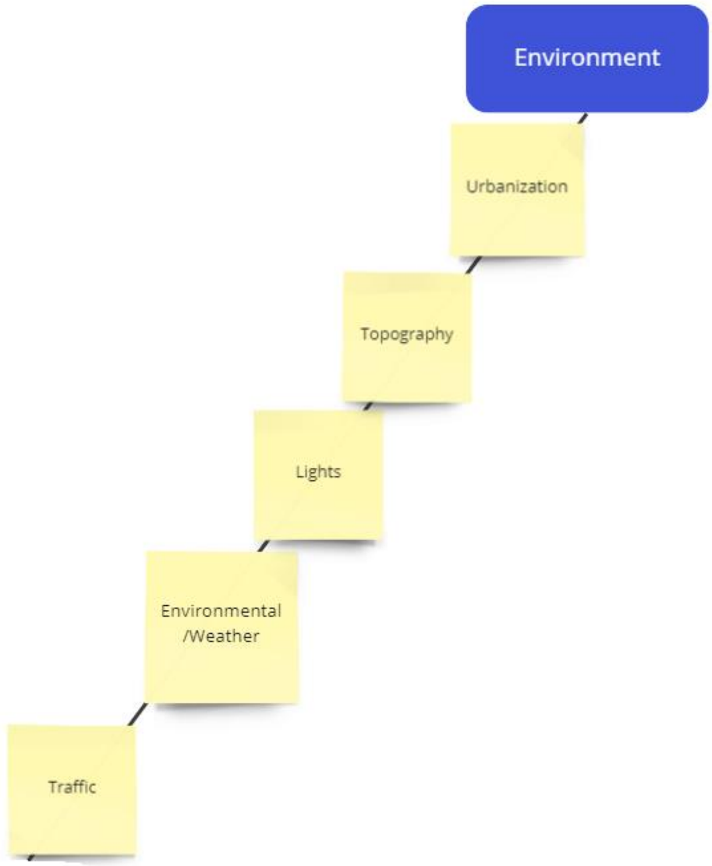


Figure 16 Environment Branch

The environment can be an element that can affect the customer experience, several risks have been identified that could affect the project:

- Traffic: Traffic can affect the driver's driving experience (process risk);
- Environmental/Weather: the risk that there may be dangerous weather, more generally the risk that there may be climatic or environmental impediments to the provision of the service (hybrid risk);
- Lights: City lights can affect the driver's visibility during the driving experience while driving (process risk);
- Topography: The risk that the topographical surveys applied to the technical map of the city of Turin were not conducted correctly (process risk);

- Urbanization: The presence of physical elements that can disturb the driven experience of the customer, such as: not signalled roundabouts, road condition, construction sites, etc. (Process risk)

Materials

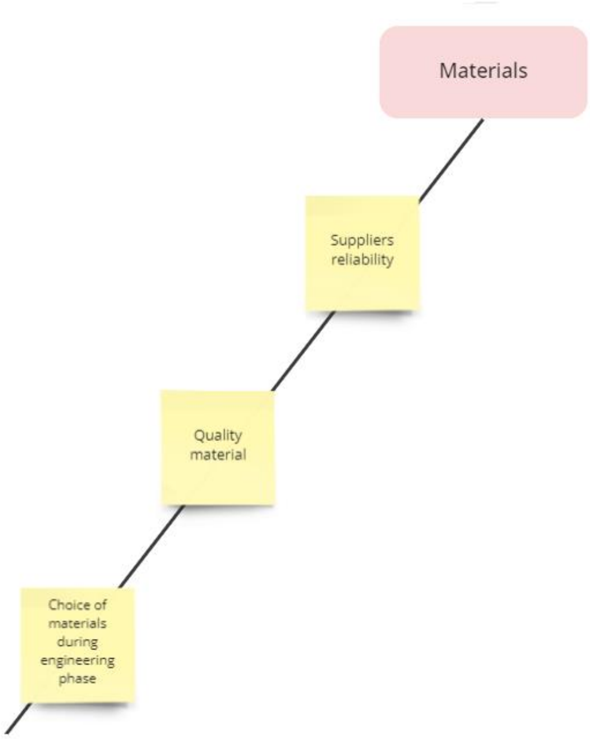


Figure 17 Materials branch

Another area where the causes of possible vehicle unsafety have been analysed is that of materials, where those ones identified are:

- Suppliers reliability: Occurs, if something during the procurement of elements to perform the service goes wrong (project risk);
- Quality materials: Risk that the material used is different from the specifications indicated in the project (project risk);
- Choice materials: It represents the risk that the choice of materials during the engineering phase is incorrect (project risk).

Personnel

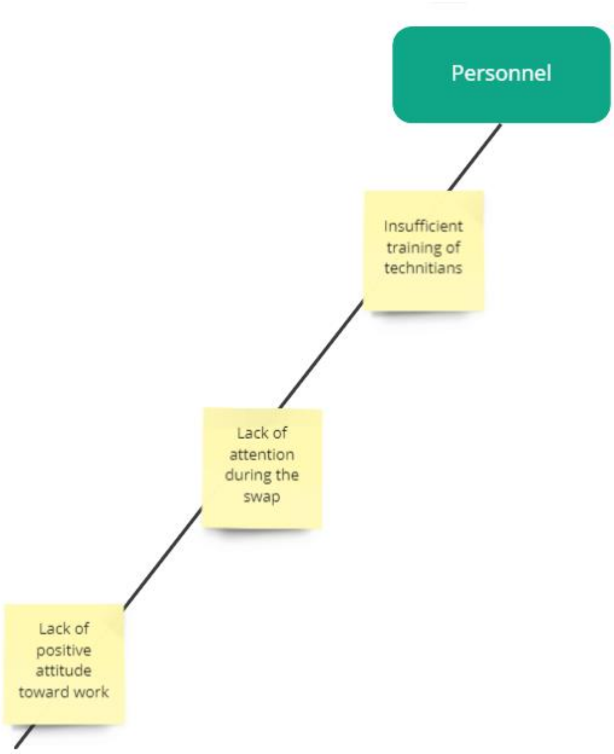


Figure 18 Personnel Branch

Within the Personnel, the risks shown in the image above have been identified. These are mainly process risks. They are reported in the following lines:

- Insufficient training of technicians: It represents the risk that the technicians are not trained properly to perform the work during the swap service (hybrid risk);
- Lack of attention during swap: It represents the risk that technicians do not take care enough about the work to perform (process risk);
- Lack of positive attitude toward work: It represents the risk that technicians do not take care enough about the work to perform (hybrid risk).

Driver

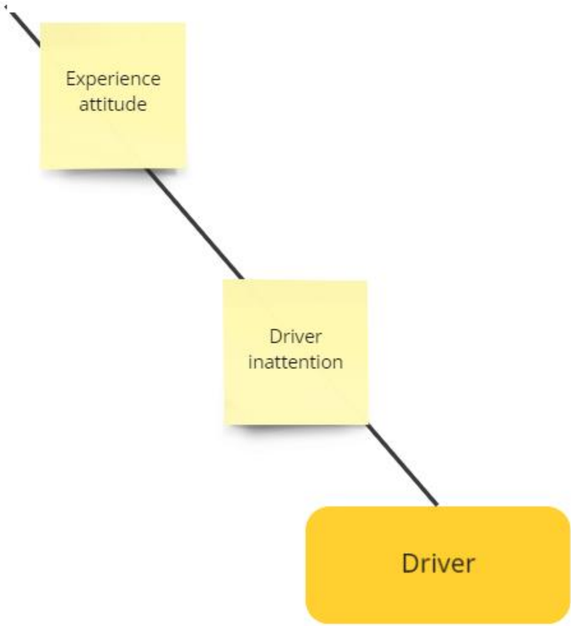


Figure 19 Driver Branch

In this section of the diagram has been analysed risks that may arise from the characteristics of the driver during the usufruition of the services, such as:

- Experience attitude: Experience to drive of customer (process risk);
- Driver inattention: Accident due to driver inattention like: anxiety or inappropriate physical condition (process risk).

2.1.2.2 SWOT Analysis

SWOT analysis is a managerial tool used to analyse the influence of internal factors (strengths and weaknesses) and external factors (opportunities and threats) on the project. This makes it possible to outline the shape of the present and future organisation by identifying its risks.

The following SWOT analysis has the aim to evaluate the service provided by the car-sharing project and going more depth the process of battery swap, in fact some of the risks found below for internal factors have influence on both process and project. This happen because most of the process risks participate in the commissioning phase of the project. However, as in the previous analysis for each risk it will be indicated if it is involved in hybrid (both process and project), project or process field.

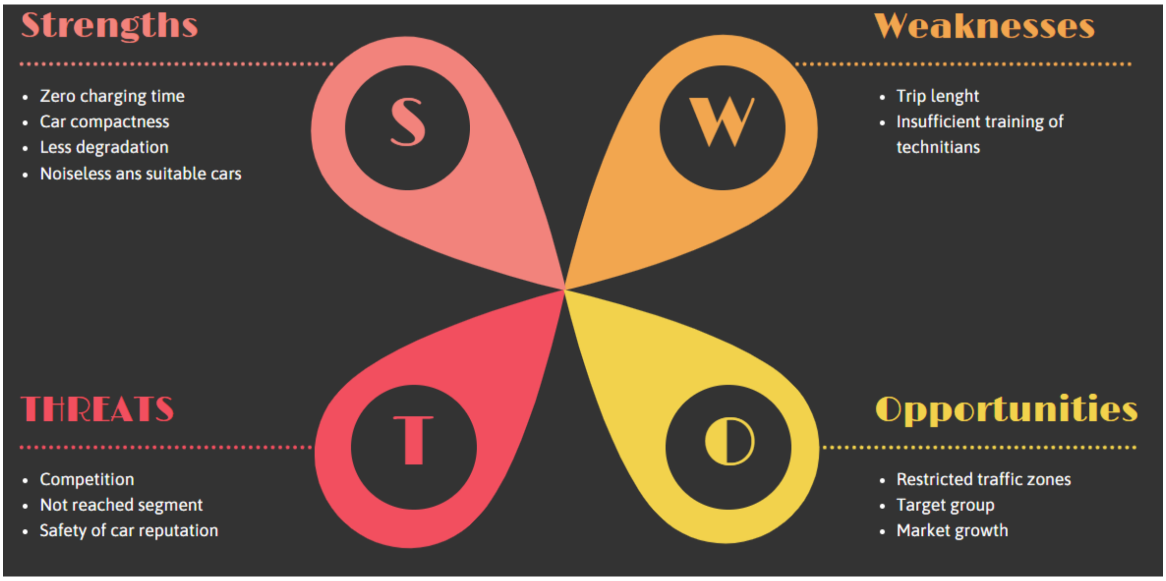


Figure 20 SWOT Analysis

The risks identified section by section are explained below:

Strenghts

- Zero charging time: Charging time is cancelled thanks to battery swap service (hybrid risk);
- Car compactness: Small and compact micro EVs to deal with travelling and parking in the city (hybrid risk);

- Less degradation: Less degradation of EVs components compared to other types of cars and consequently less maintainability costs (hybrid risk);
- Noiseless and sustainable cars: The micro EVs do not emit noises or vibrations, therefore they have zero emissions of CO2 (hybrid risk).

Weaknesses

- Trip length: It represents the risk that the vehicle can stop during a long trip, since Micro EVs are not suitable for this kind of rides (process risk);
- Insufficient training of technicians: It represents the risk that the technicians are not well trained to perform the work during the swap service (hybrid risk);

Threats

- Competition: This refers to the threats of other battery charging projects and battery swaps, thus of those businesses that are considered competitors. There are several entities in the current market for charging structures (Biro Estrima, Tazzari ZZero Junior, Aixam City Pack, Citroen Ami) (project risk);
- Not reached segment: More conservative people will not join the swap project now, especially segments of market like laggards in the Rogers Adoptive Curve (project risk);
- Safety of car reputation: small cars are therefore easier to destroy than the medium size cars (theme exploited in the Ishikawa Diagram).

Opportunities

- Restricted traffic zones: Electric microcars can enter restricted traffic zones (such as Area C in Milan and Via Garibaldi in Turin) free of charge (project risk);
- Target group: The extension of target group beyond teenagers to workers in big cities (project risk);
- Market growth: The society of the future will become sustainable, and these technologies will be increasingly in vogue (project risk).

2.1.3 Risk Breakdown Structure

The Risk Breakdown Structure below lists and classifies the risks associated with the project against the different levels that comprise the structure.

LEVEL 0	LEVEL 1	LEVEL 2
ALL SOURCES OF PROJECT RISK	TECHNICAL RISKS	SCOPE DEFINITION
		REQUIREMENTS' DEFINITION
		ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS
		TECHNOLOGY
		FAILURES OF COMPONENTS
		MAINTENANCE
		LESS DEGRADATION
		UNSATISFACTORY SWAP SERVICE
		QUALITY MATERIALS
		CHOICE OF MATERIALS
		TRIP LENGTH
	PROJECT MANAGEMENT RISK	COMPLETION RISK
		RELATED PROGRAM/PORTFOLIO MANAGEMENT
		INADEQUATE MANAGEMENT EXPERIENCE
		OPERATIONS MANAGEMENT
		RESOURCING
		LACK OF COMMUNICATION
		MISALLOCATION OF RIGHTS AND RESPONSIBILITIES
		POOR FUND SUPERVISION
	ECONOMIC/MARKET RISKS	FINANCIAL RISK
		INFLATION
		REVENUE RISK

		COMPETITION
		MARKET GROWTH
		NOT REACHED SEGMENT
		TARGET GROUP
	COMMERCIAL RISK	CONTRACTUAL TERMS AND CONDITIONS
		SUPPLIERS RELIABILITY
		PARTNERSHIPS AND JOINT VENTURES
	SOCIAL/ENVIRONMENT RISKS	PUBLIC OPPOSITION
		ENVIRONMENTAL RISK
		NOISELESS AND SUSTAINABLE CARS
		TRAFFIC
		LIGHTS
		TOPOGRAPHY
		URBANIZATION
		CAR COMPACTNESS
		RESTRICTED TRAFFIC ZONES
	EXTERNAL RISKS	CHANGE IN POLICY AND LAW (LEGILATION)
		DELAYS IN PROJECT APPROVALS AND PERMITS
		EXCHANGE RATES
		SITE/FACILITIES
		ENVIRONMENTAL/WEATHER

Table 1 Project Risk Breakdown Structure

In the following table there are all the descriptions of the identified risks that are related to the Project.

RISK NAME	**RISK DESCRIPTION**
SCOPE DEFINITION	Changes in the scope may arise during the development of the project or redundant scopes may be discovered.
REQUIREMENTS' DEFINITION	What the customer wants to achieve or the usage the customer wants to attribute to the service changes over

	time.
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS	The foresight assumed are not considered trustworthy.
TECHNOLOGY	The risk may arise if the technology becomes obsolete.
FAILURES OF COMPONENTS	There could be some failures in the components involved in the swap of the battery during the extraction or insertion phases.
MAINTENANCE	The risk that some maintenance procedures are not executed properly.
LESS DEGRADATION	Less degradation of components and less maintainability compared to other types of cars.
UNSATISFACTORY SWAP SERVICE	This refers to the quality and efficiency of the swap service which is unable to meet the demand of EV drivers, which directly affects the project's income.
QUALITY MATERIALS	Risk that the material used is different from the specifications indicated in the project.
CHOICE OF MATERIALS	It represents the risk that the choice of materials during the engineering phase is incorrect.
TRIP LENGTH	It represents the risk that the vehicle can stop during a long trip, since Micro EVs are not suitable for this kind of rides.
COMPLETION RISK	This refers to the risk that the project cannot be completed within the planned timeframe due to insufficient staffing, financial difficulties, inadequate management experience, and so on.
RELATED PROGRAM/PORTFOLIO MANAGEMENT	The impact that the issues/opportunities of the current project may have on all other related projects or on the whole portfolio of firm.
INADEQUATE MANAGEMENT EXPERIENCE	The management board could not have the proper experience on this kind of project, then this led to human errors.

OPERATIONS MANAGEMENT	The risk of loss resulting from ineffective or failed internal processes, people, systems, or external events that may disrupt the flow of business operations.
RESOURCING	It is related to the possibility to have lack/absence of critical resources like charged batteries, raw materials for stations or technicians.
LACK OF COMMUNICATION	It indicates the risk that there is poor communication between operators inside the project or a lack of communication towards external entities.
MISALLOCATION OF RIGHTS AND RESPONSIBILITIES	Agreements loosely define responsibilities and commitments, which causes alterations and shirks their responsibilities.
POOR FUND SUPERVISION	Inadequate supervision of funds can lead to a loss of control over their use, which will result in indiscriminate use of funds and subsidies.
FINANCIAL RISK	Insufficient funds and change of interest rates interested from banks' loans, since this type of projects requires copious amounts of funds.
INFLATION	A rise in the price level leads to a reduction of purchasing power in terms of money and then increase staff cost and materials prices, increasing construction and operating costs.
REVENUE RISK	It represents the risk that the profits are lower than the anticipated revenue. This is since this type of innovation is still not in the stage of maturity, then the market price of the services can be initially lower than the cost to provide it.
COMPETITION	This refers to the threats of other battery charging projects and battery swaps, thus of those businesses that can be considered competitors. There are several entities in the current market that can copy the service of swap charging structures (Biro Estrima, Tazzari ZZero Junior,

	Aixam City Pack, Citroen Ami).
MARKET GROWTH	The society of the future will become sustainable, and these technologies will be increasingly in vogue.
NOT REACHED SEGMENT	More conservative people will not join the swap project now, especially segments of market like laggards in the Rogers Adoptive Curve.
TARGET GROUP	The extension of target group beyond teenagers (16+) to workers in big cities.
CONTRACTUAL TERMS AND CONDITIONS	It occurs if the contracts are not done properly and there is the verification of conditions not defined in the contracts.
SUPPLIERS RELIABILITY	Occurs, if something during the procurement of elements to perform the service goes wrong (project risk);
PARTNERSHIPS AND JOINT VENTURES	It represents the possibility which occur other new partnerships or joint ventures.
PUBLIC OPPOSITION	This risk stems from public opposition due to improper site selection and eventual safety concerns.
ENVIRONMENTAL RISK	It indicates types of pollution as noise and dust during the construction stage, will bring negative effects to the project.
NOISELESS AND SUSTAINABLE CARS	The micro EVs do not emit noises or vibrations, therefore they have zero emissions of CO_2.
TRAFFIC	Traffic can affect the driver's driving experience.
LIGHTS	City lights can affect the driver's visibility during the driving experience while driving.
TOPOGRAPHY	The risk that the topographical surveys applied to the technical map of the city of Turin were not conducted correctly.
URBANIZATION	The presence of physical elements that can disturb the driven experience of the customer, such as: roundabouts, road condition, construction sites, etc.).

CAR COMPACTNESS	The micro-EV is small and compact, perfectly in line with actual requirements of the customers in big cities.
RESTRICTED TRAFFIC ZONES	Electric microcars can enter restricted traffic zones (such as Area C in Milan and Via Garibaldi in Turin) free of charge.
CHANGE IN POLICY AND LAW (LEGISLATION)	Change of legislation concerning electric microcars and battery swaps.
DELAYS IN PROJECT APPROVALS AND PERMITS	This refers to the fact that the bureaucratic process of permits is often complicated, which causes less time efficiency that can affect the project.
EXCHANGE RATES	The risk of a change in value between two monetary currencies during transactions to purchase equipment and materials.
SITE/FACILITIES	It indicates the possibility that a certain site or facility is not suitable for the storage of charged battery or is not comfortable to provide the service of swap battery.
ENVIRONMENTAL/WEATHER	The risk that there may be dangerous weather, more generally the risk that there may be climatic or environmental impediments to the provision of the service.

Table 2 Project risks description

2.2 Analysis of the process

This section defines the step-by-step process of battery SWAP at the charging station. The real innovation in this project is the elimination of charging time when the batteries need to be recharged. In fact, the customer can go directly to the charging station, where specialised technicians will serve him, and have his discharged batteries exchanged for charged ones in a very short time. In this way the user benefits from the service in a very simple and fluid way, without having to wait for the battery to be charged.

2.2.1 Process Map

The Process Map is a tool that establishes the flowchart of the process through the individual steps. It shows who and what is involved in a process and may reveal areas in which a process should be improved.

The battery swap process map has two actors: Customer and Technician.In the following diagram, the map is divided in three phases.

Initial phase

In the initial phase it starts with the customer arriving at the service station, then there is a decision-making step where he has to decide whether he wants to use the battery swap service or not. If yes, the technician takes the empty batteries and checks that they are in good condition; if not, the customer swaps the microcar for the nearest free one or waits for the batteries to be charged at the service station.

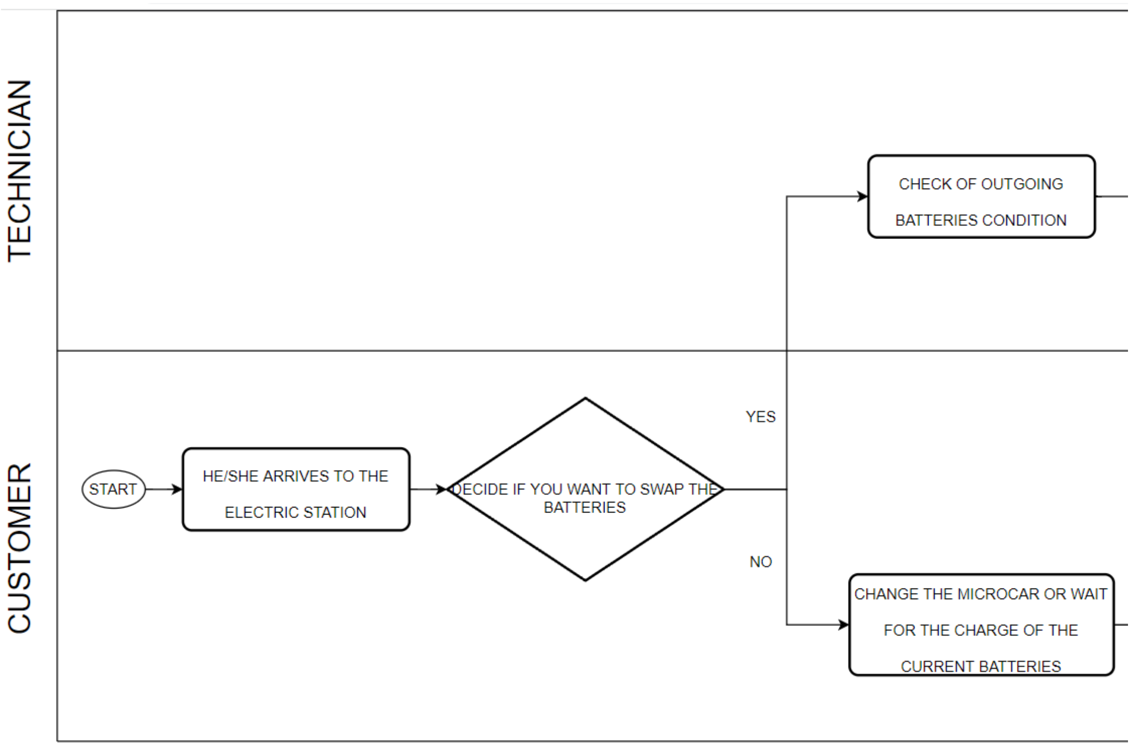


Figure 21 Initial Phase Process Map

Intermediate phase

In the intermediate phase there is a decision-making step on the upper side, where the technician assesses the state of health of the batteries. If the result is positive, he goes to the charging storage and exchanges the charged batteries with the discharged ones he has just detected. If the result is negative, he reports faults to the maintenance centre and takes new batteries for the micro HV.

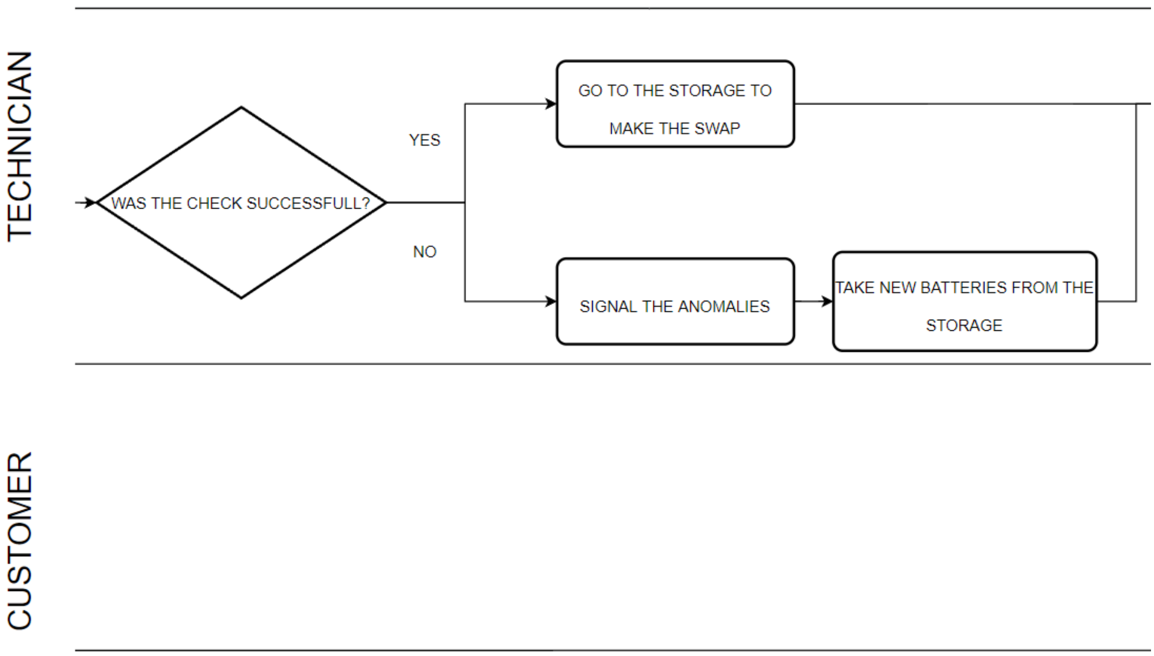


Figure 22 Intermediate Phase Process Map

Final phase

In the final stage the technician returns to the micro HV and inserts the charged batteries into the vehicle, after which the process ends with the departure and use of the vehicle by the customer.

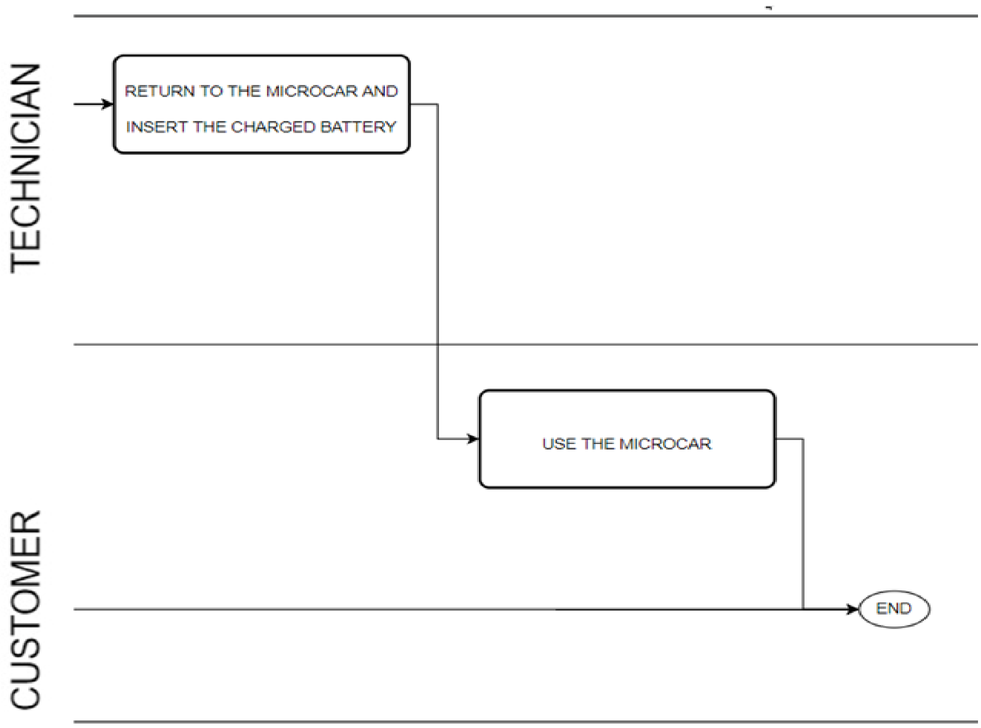


Figure 23 Final Phase Process Map

2.2.2 Risks identification

Process risks are all those risks related to the individual activities described in the Process Map. They have been identified through the use of the ABM (agent-based model), used to simulate the behaviour of autonomous agents in the system and the interaction between them.

The following pictures shows the possible risks for each activity.

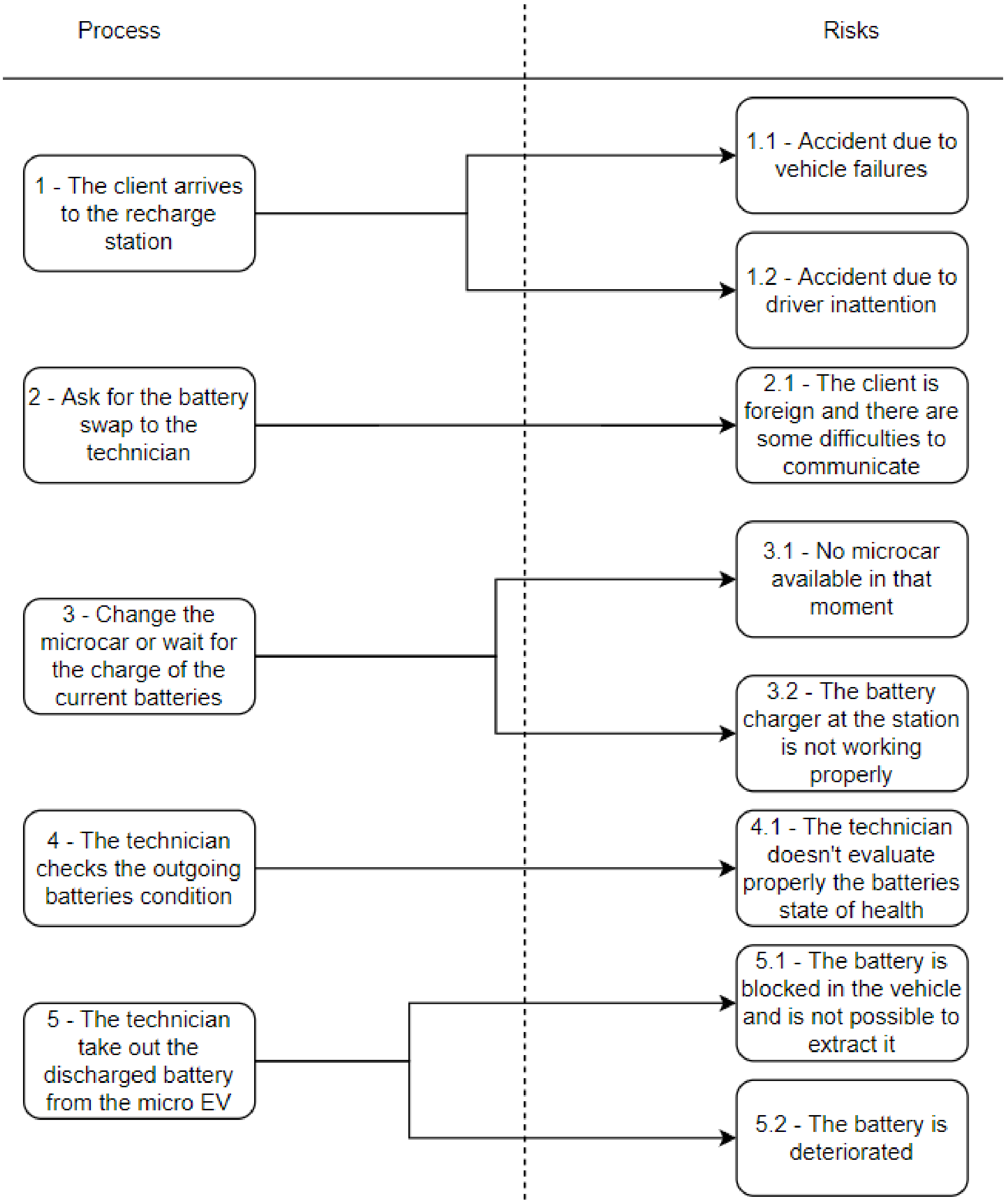


Figure 24 Agent-Based Model Part one

In each of the first five steps of the process, the following risks were identified:

- Failure accidents: Accident due to vehicle failures;
- Driver inattention: Accident due to driver inattention (anxiety, physical condition);
- Different language: A foreign client does not know the home country language and there could be some problems in the communication with the technician;
- No microcar available: There are not micro HV available in the case where the user don't want to use the swap service;

- Wrong check of battery state: It represents the risk that during the check of the battery health something is not executed properly;
- Deterioration: The batteries extracted from the micro HV are deteriorated;
- Blocked battery: The battery is blocked in the vehicle and is not possible to extract it.

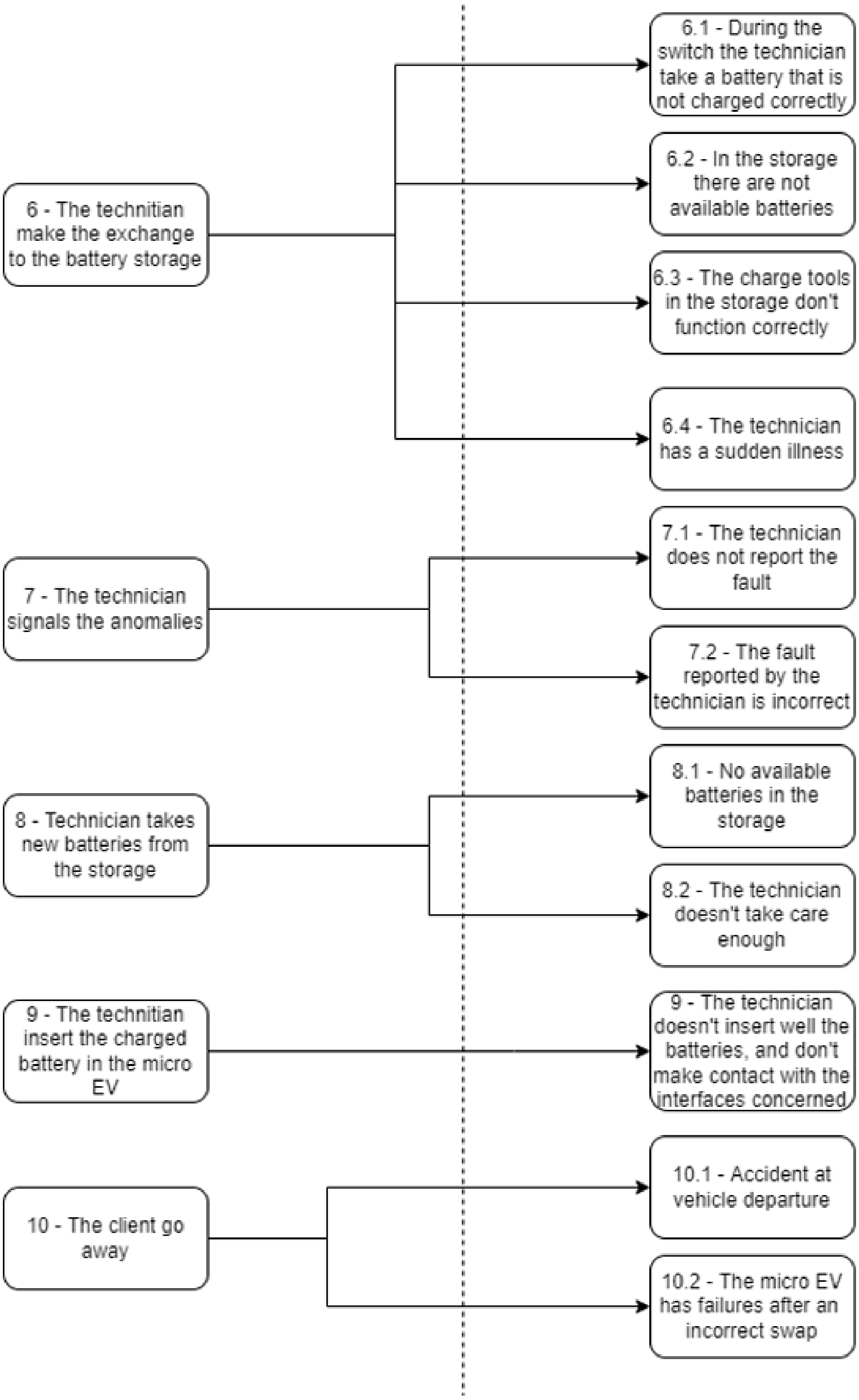


Figure 25 Agent-Based Model Part two

As regard the last five steps of the process, the following risks were identified:

- Dysfunctionality in charging: During the switch, the technician takes a battery that is not charged correctly;
- No availability of batteries: In the battery storage there are not available batteries;
- Technician illness: The technician has a sudden illness;
- Lack of positive attitude toward work: It represents the risk that technicians do not take care enough about the work to perform (contain 7.1, 7.2 and 8.2);
- Wrong insertion of charged batteries: The technician does not insert well the batteries, and do not make contact with the interfaces concerned;
- Departure accident: It happens an accident in the departure phase after the swap.

2.3 Qualitative Analysis

In the qualitative analysis carried out on the project and process, values from 1 to 5 (likelihood and impact) were assigned to each link between risk and work package.

To identify to which work packages refers each risk, they will be associated with an ID code in the table below:

ID CODE	**WORK PACKAGE**
1	**ENGINEERING**
1.1	BASIC DESIGN
1.2	DETAILED ENGINEERING
1.3	SUBMISSION AND APPROVAL OF ENGINEERING SET OF DRAWINGS
2	**AGREEMENTS**
2.1	PARTNERS’ AGREEMENTS
2.2	AGREEMENTS WITH PUBLIC ENTITIES
3	**PROCUREMENT**
3.1	PROCUREMENT OF THE NECESSARY MATERIAL FOR THE FACILITY CONSTRUCTION
3.2	PROCUREMENT OF THE NECESSARY EVs
4	**BUILDING AND CIVIL WORKS**

4.1	CLEARING SITES FOR THE NEW STATIONS
4.2	**CONSTRUCTION OF CHARGING STATION SITES**
4.2.1	SITE PREPARATION
4.2.2	FOUNDATIONS
4.2.3	STATION ERECTION
4.3	UPGRADE STATIONS
5	**EMPLOYEES**
5.1	TRAINING AND RECRUITING OF TECHNICIANS
6	**COMMISSIONING**
6.1	DELIVERING AND TESTING OF THE SERVICE
CH1	CUSTOMER ARRIVES TO THE ELECTRIC STATION (OR DEPARTURE FROM THE STATION)
CH2	EXTRACTION OF THE DISCHARGED BATTERIES
CH3	CHECK OF OUTGOING BATTERIES CONDITION
EM1	TECHNICIAN GOES TO THE STORAGE TO MAKE THE SWAP
EM2	SIGNALING EVENTUAL ANOMALIES
EM3	VEHICLE OR BATTERY IMMEDIATE MAINTENANCE
EM4	THE TECHNICIAN SENDS THE FAULTY COMPONENTS TO THE REPAIR CENTRES
EM5	TAKE NEW BATTERIES FROM THE STORAGE
EM6	RETURN TO THE MICROCAR AND INSERT THE CHARGED BATTERY
UE1	THE CUSTOMER DRIVES A SHORT ROUTE
UE2	THE CUSTOMER DRIVES A LONG ROUTE

Table 3 Identification codes of the WBS

The following table shows the assigned probability (P) and impact (I) values for each risk related with the indicated Work Packages expressed in form of ID code.

RISK NAME	QUALITATIVE EVALUATION ON WPs
SCOPE DEFINITION	1.1 → P = 2 ; I = 1 1.2 → P = 2 ; I = 1 1.3 → P = 2 ; I = 1 2.1 → P = 1 ; I = 1 2.2 → P = 1 ; I = 1 3.1 → P = 1 ; I = 2 3.2 → P = 1 ; I = 2 4.1 → P = 1 ; I = 1 4.2.1 → P = 1 ; I = 1 4.2.2 → P = 1 ; I = 3 4.2.3 → P = 1 ; I = 3 4.3 → P = 1 ; I = 3 5.1 → P = 1 ; I = 3 6.1 → P = 1 ; I = 3
REQUIREMENTS' DEFINITION	2.1 → P = 2 ; I = 2 2.2 → P = 2 ; I = 2 3.1 → P = 2 ; I = 3 3.2 → P = 2 ; I = 3 5.1 → P = 2 ; I = 3 6.1 → P = 3 ; I = 4 CH3 → P = 2 ; I = 3 EM2 → P = 2 ; I = 3
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS	2.1 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3 3.1 → P = 2 ; I = 4 3.2 → P = 2 ; I = 4 5.1 → P = 2 ; I = 3

TECHNOLOGY	6.1 → P = 1 ; I = 4
FAILURES OF COMPONENTS	CH2 → P = 2 ; I = 4 EM4 → P = 2 ; I = 4 EM6 → P = 2 ; I = 4
MAINTENANCE	EM2 → P = 2 ; I = 4 EM3 → P = 2 ; I = 4 EM4 → P = 2 ; I = 4
LESS DEGRADATION	6.1 → P = 5 ; I = 3 CH2 → P = 5 ; I = 1 EM3 → P = 5 ; I = 3 EM4 → P = 5 ; I = 3
UNSATISFACTORY SWAP SERVICE	6.1 → P = 2 ; I = 4
QUALITY MATERIALS	3.1 → P = 2 ; I = 4 3.2 → P = 2 ; I = 4 4.2 → P = 2 ; I = 5 4.2.1 → P = 2 ; I = 5 4.2.2 → P = 2 ; I = 5 4.2.3 → P = 2 ; I = 5
CHOICE OF MATERIALS	1.1 → P = 2 ; I = 4 1.2 → P = 2 ; I = 4 1.3 → P = 2 ; I = 4
TRIP LENGTH	6.1 → P = 2 ; I = 4 UE2 → P = 2 ; I = 4
COMPLETION RISK	3.1 → P = 4 ; I = 3 3.2 → P = 4 ; I = 3 4.1 → P = 4 ; I = 4 4.2 → P = 4 ; I = 4 4.2.1 → P = 4 ; I = 4 4.2.2 → P = 4 ; I = 4 4.2.3 → P = 4 ; I = 4
RELATED PROGRAM/PORTFOLIO MANAGEMENT	3.2 → P = 2 ; I = 3 5.1 → P = 2 ; I = 3

	6.1 → P = 2 ; I = 3
INADEQUATE MANAGEMENT EXPERIENCE	2.1 → P = 1 ; I = 3 2.2 → P = 1 ; I = 3 3.1 → P = 1 ; I = 3 3.2 → P = 1 ; I = 3 6.1 → P = 1 ; I = 3
OPERATIONS MANAGEMENT	2.1 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3 3.1 → P = 2 ; I = 3 3.2 → P = 2 ; I = 3 5.1 → P = 2 ; I = 3 6.1 → P = 2 ; I = 3
RESOURCING	3.1 → P = 1 ; I = 4 3.2 → P = 1 ; I = 4 EM5 → P = 1 ; I = 4 EM6 → P = 1 ; I = 4
LACK OF COMMUNICATION	1.1 → P = 2 ; I = 3 1.2 → P = 2 ; I = 3 1.3 → P = 2 ; I = 3 2.1 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3 3.1 → P = 2 ; I = 4 3.2 → P = 2 ; I = 4 4.1 → P = 2 ; I = 3 4.2 → P = 2 ; I = 3 4.2.1 → P = 2 ; I = 3 4.2.2 → P = 2 ; I = 3 4.2.3 → P = 2 ; I = 3 5.1 → P = 3 ; I = 3 EM2 → P = 2 ; I = 4 EM4 → P = 2 ; I = 4
MISALLOCATION OF RIGHTS AND	2.1 → P = 1 ; I = 3

RESPONSIBILITIES	2.2 → P = 1 ; I = 3
POOR FUND SUPERVISION	3.1 → P = 2 ; I = 3 3.2 → P = 2 ; I = 3 4.1 → P = 2 ; I = 3 4.2 → P = 2 ; I = 3 4.2.1 → P = 2 ; I = 3 4.2.2 → P = 2 ; I = 3 4.2.3 → P = 2 ; I = 3 6.1 → P = 2 ; I = 3
FINANCIAL RISK	2.1 → P = 1 ; I = 4 2.2 → P = 1 ; I = 4 3.1 → P = 1 ; I = 4 3.2 → P = 1 ; I = 4 5.1 → P = 1 ; I = 4
INFLATION	2.1 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3 3.1 → P = 2 ; I = 3 3.2 → P = 2 ; I = 3 5.1 → P = 2 ; I = 3 6.1 → P = 2 ; I = 3
REVENUE RISK	6.1 → P = 2 ; I = 3
COMPETITION	6.1 → P = 5 ; I = 3
MARKET GROWTH	6.1 → P = 3 ; I = 4
NOT REACHED SEGMENT	6.1 → P = 3 ; I = 2
TARGET GROUP	6.1 → P = 4 ; I = 3
CONTRACTUAL TERMS AND CONDITIONS	2.1 → P = 1 ; I = 4 2.2 → P = 1 ; I = 4
SUPPLIERS RELIABILITY	3.1 → P = 2 ; I = 4 3.2 → P = 2 ; I = 4
PARTNERSHIPS AND JOINT VENTURES	2.1 → P = 1 ; I = 4
PUBLIC OPPOSITION	4.1 → P = 1 ; I = 3

	4.2 → P = 1 ; I = 3 4.2.1 → P = 1 ; I = 3 4.2.2 → P = 1 ; I = 3 4.2.3 → P = 1 ; I = 3
ENVIRONMENTAL RISK	4.1 → P = 5 ; I = 2 4.2 → P = 5 ; I = 2 4.2.1 → P = 5 ; I = 2 4.2.2 → P = 5 ; I = 2 4.2.3 → P = 5 ; I = 2
NOISELESS AND SUSTAINABLE CARS	6.1 → P = 5 ; I = 5 CH1 → P = 5 ; I = 3 UE1 → P = 5 ; I = 3 UE2 → P = 5 ; I = 3
TRAFFIC	CH1 → P = 5 ; I = 2 UE1 → P = 5 ; I = 2 UE2 → P = 5 ; I = 2
LIGHTS	CH1 → P = 5 ; I = 2 UE1 → P = 5 ; I = 2 UE2 → P = 5 ; I = 2
TOPOGRAPHY	UE1 → P = 2 ; I = 1 UE2 → P = 2 ; I = 1
URBANIZATION	CH1 → P = 3 ; I = 2 UE1 → P = 3 ; I = 2 UE2 → P = 3 ; I = 2
CAR COMPACTNESS	6.1 → P = 5 ; I = 4 CH1 → P = 5 ; I = 3 UE1 → P = 5 ; I = 4 UE2 → P = 5 ; I = 1
RESTRICTED TRAFFIC ZONES	6.1 → P = 5 ; I = 3 UE1 → P = 4 ; I = 3
CHANGE IN POLICY AND LAW (LEGILATION)	2.1 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3

DELAYS IN PROJECT APPROVALS AND PERMITS	1.3 → P = 2 ; I = 3 2.2 → P = 2 ; I = 3
EXCHANGE RATES	2.2 → P = 3 ; I = 2 3.1 → P = 3 ; I = 2
SITE/FACILITIES	4.1 → P = 1 ; I = 4 4.2 → P = 1 ; I = 4 4.2.1 → P = 1 ; I = 4 4.2.2 → P = 1 ; I = 4
ENVIRONMENTAL/WEATHER	6.1 → P = 1 ; I = 4 CH1 → P = 1 ; I = 4 CH2 → P = 1 ; I = 4 CH3 → P = 1 ; I = 4 EM1 → P = 1 ; I = 4 EM2 → P = 1 ; I = 4 EM3 → P = 1 ; I = 4 EM4 → P = 1 ; I = 4 EM5 → P = 1 ; I = 4 EM6 → P = 1 ; I = 4
FAILURE ACCIDENTS	CH1 → P = 2 ; I = 3 CH3 → P = 2 ; I = 3 EM6 → P = 2 ; I = 3
EXPERIENCE ATTITUDE	CH1 → P = 2 ; I = 3 UE1 → P = 2 ; I = 3 UE2 → P = 2 ; I = 3
DIRVER INATTENTION	CH1 → P = 1 ; I = 3 UE1 → P = 1 ; I = 3 UE2 → P = 1 ; I = 3
DIFFERENT LANGUAGE	CH1 → P = 1 ; I = 1 EM2 → P = 1 ; I = 2
BLOCKED BATTERY	CH2 → P = 2 ; I = 3
DETERIORATION	CH3 → P = 2 ; I = 3 EM2 → P = 2 ; I = 3

	EM3 → P = 2 ; I = 3 EM4 → P = 2 ; I = 3
DYSFUNCTIONALITY IN CHARGING	EM1 → P = 2 ; I = 4 EM5 → P = 2 ; I = 4
NOT AVAILABLE BATTERIES	EM1 → P = 1 ; I = 4 EM2 → P = 1 ; I = 4 EM5 → P = 1 ; I = 4
TECHNICIAN ILLNESS	CH2 → P = 1 ; I = 5 CH3 → P = 1 ; I = 5 EM1 → P = 1 ; I = 5 EM2 → P = 1 ; I = 5 EM4 → P = 1 ; I = 5 EM5 → P = 1 ; I = 5 EM6 → P = 1 ; I = 5
WRONG INSERTION OF CHARGED BATTERIES	EM6 → P = 1 ; I = 4
DEPARTURE ACCIDENT	CH1 → P = 1 ; I = 4
INSUFFICIENT TRAINING OF TECHNICIANS	5.1 → P = 2 ; I = 4 CH3 → P = 2 ; I = 5 EM1 → P = 2 ; I = 5 EM2 → P = 2 ; I = 5 EM4 → P = 2 ; I = 5 EM5 → P = 2 ; I = 5 EM6 → P = 2 ; I = 5
LACK OF POSITIVE ATTITUDE TOWARD WORK	5.1 → P = 2 ; I = 3 CH2 → P = 2 ; I = 3 CH3 → P = 2 ; I = 3 EM1 → P = 2 ; I = 3 EM2 → P = 2 ; I = 3 EM4 → P = 2 ; I = 3 EM5 → P = 2 ; I = 3 EM6 → P = 2 ; I = 3

NO MICROCAR AVAILABLE	CH1 → P = 1 ; I = 4
WRONG CHECK OF BATTERY STATE	CH3 → P = 2 ; I = 5
ZERO CHARGING TIME	6.1 → P = 5 ; I = 4 EM6 → P = 5 ; I = 3

Table 4 Qualitative analysis evaluation

2.4 Battery pack analysis

In this paragraph the battery pack of the electric microcar is represented and analyzed via FMECA, considered the most influential element during the battery SWAP to the charging station.

2.4.1 Composition of battery pack

The battery pack is a subsystem that is carefully examined to understand how faults can occur on individual components and how the HV can be affected.

The following image shows a basic representation of how the battery pack is constructed.

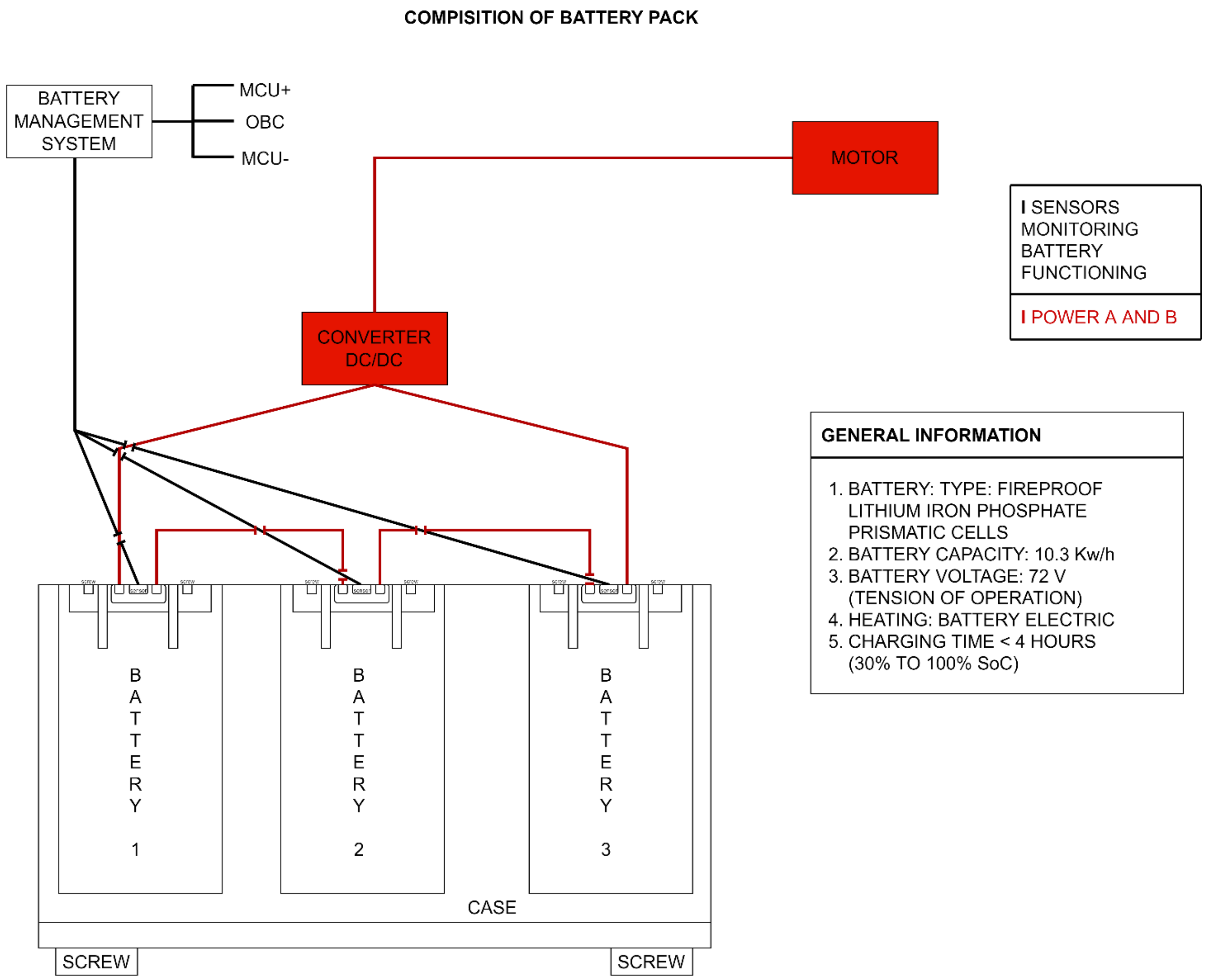


Figure 26 Representation of battery pack

There are three lithium batteries with series connection. They use power connectors and sensor connectors, in addition to centring pins used to provide mechanical support for the battery, without placing it completely on screws or connectors. The sensor connectors are wired to a Battery Management System which acts as the mind of the battery pack and evaluates all the input data provided by the sensors. The power connectors, on the other hand, are connected by cables to the converter, which manages the voltage of the electrical current flowing to the motor.

2.4.2 Functionality Block Diagram

The FBD (Functionality Block Diagram) is a tool used to describe how a system operates and all the interrelationships between the components.

The diagram below describes the division of the system in the red zone (electric current side) and green zone (sensors' signals side), represented by R-components and how they operate together.

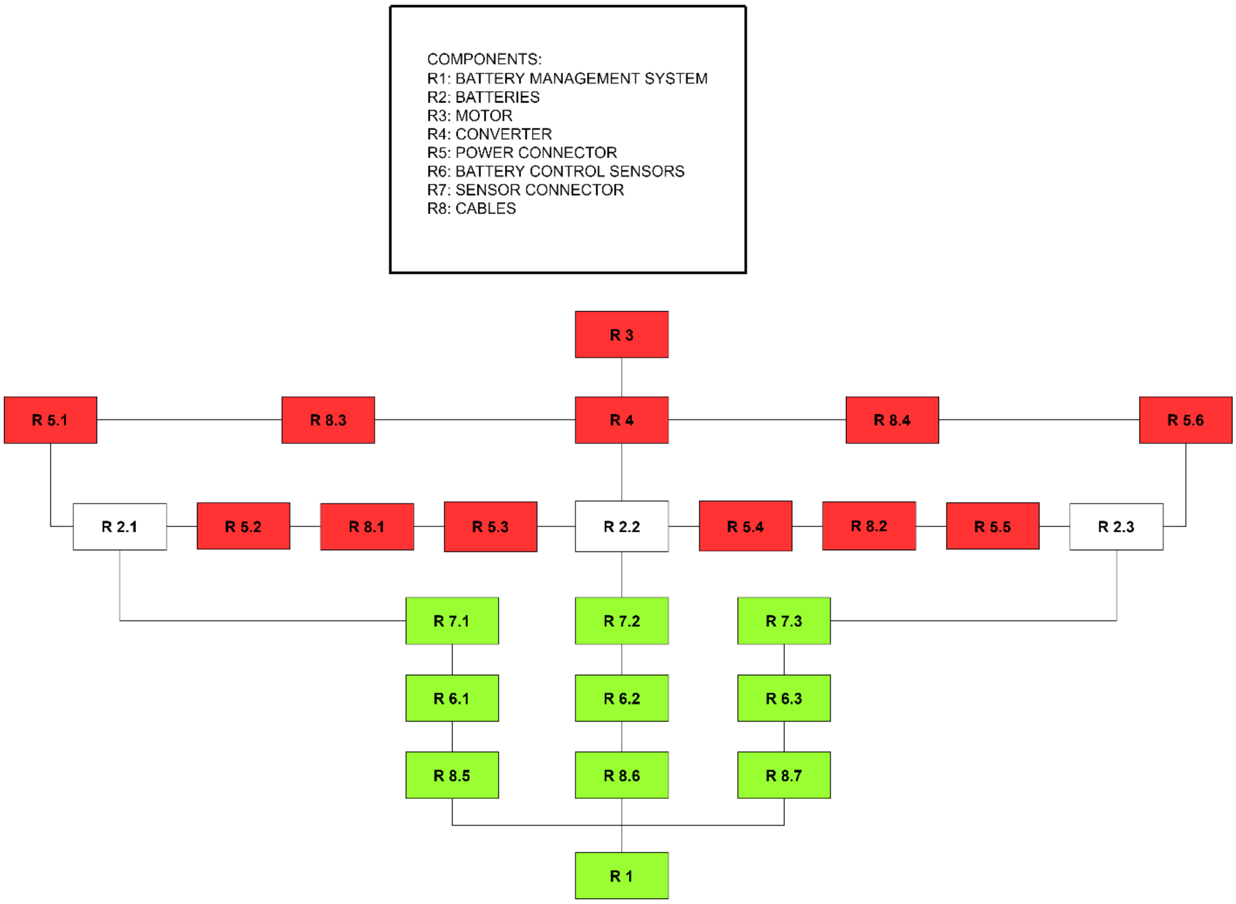


Figure 27 Functionality Block Diagram

In this block diagram it can be seen that there are two parts connected to the battery pack: one connected to the sensors and one connected to the electric current.

In the central block, which runs from R 2.1 to R 2.3, the electrical current circulates between the batteries in series, until it reaches the extremes, where the cables lead up to the converter, which first operates on the voltage and then delivers the electrical current to the motor. On the other hand, in the lower part it is possible to see how there is a unidirectional flow of data acquired by the sensors to the BMS via cables.

2.4.3 FMECA (Failure Mode and Effect Criticality Analisys)

In this section, through the use of an FMECA proposed by Teoresi Group Spa, on the basis of the one presented in chapter 1 , the faults that may be present on the battery pack have been analysed. The FMECA analysis it is divided into the following sections:

Component Name, Component Function, Operation Mode, Component failure rate, Failure mode percentage, Failure mode, Failure cause, Local effects, System effects, Vehicle effects (Reliability), Vehicle effects (Safety), Detection, Maintenance, Mitigation, Failure mode failure rate, Frequency, Severity, Criticality.

Quantitative data on component failure rates are taken from Teoresi Group Spa databases; they are based on vehicle components used for similar projects.

Frequency classification is associated with failure mode failure rate values, categorized as follows:

Frequent	>1e-3
Probable	<1e-3
Occasional	<1e-4
Rare	<1e-5
Improbable	<1e-7
Highly improbable	<1e-9

Table 5 Frequency categorization table of electric automotive industry

While the failure mode classification is constructed based on the following table:

Frequency of occurrence of an accident (caused by a hazard)	Risk Acceptance Categories			
Frequent	Undesirable	Intolerable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Intolerable	Intolerable
Occasional	Tolerable	Undesirable	Undesirable	Intolerable
Rare	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Undesirable
Highly improbable	Negligible	Negligible	Negligible	Tolerable
	Insignificant	Marginal	Critical	Catastrophic
	Severity of an accident (caused by a hazard)			

Table 6 Risk acceptance categories based on electric automotive industry

For space reasons, each row has been divided in three parts that are presented in a subsequent way. Therefore the FMECA excel table has been divided into several section per component:

2.4.3.1 Battery

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode
BATTERY	PROVIDES ELECTRICAL CURRENT TO POWER THE MOTOR OF THE MICRO-HV	ALL	3,00E-05	50%	CONNECTOR OXIDATION
		MICROCAR IN USE OR MAINTENANCE	3,00E-05	25%	STRUCTURAL (MECHANICAL) BATTERY DAMAGE
		ALL	3,00E-05	25%	INTERNAL BATTERY (ELECTRICAL) DAMAGE

Failure Cause	Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)
WEAR AND TEAR AND LACK OF PROPER MAINTENANCE	BAD CONTACT AND THE CONNECTOR GETS OVERHEATED	THE POWER IS NOT THE REQUIRED ONE	TO BE DEFINED	TO BE DEFINED
VIBRATION AND MECHANICAL SHOCK THAT COULD HAPPEN DURING THE TRIPS OR DURING THE BATTERY SWAP	BATTERY IS LEAKING LIQUID	REDUCED BATTERY PERFORMANCE	TO BE DEFINED	TO BE DEFINED
ELECTRICAL OR MECHANICAL SHOCK	BATTERY PERFORMANCE GOES DOWN	REDUCED BATTERY PERFORMANCE	TO BE DEFINED	TO BE DEFINED

Detection	Maintenance	Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
DURING MAINTENANCE, DURING USE OF THE VEHICLE IF THERE IS A MALFUNCTION OR DURING BATTERY SWAP	NOT GIVEN	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE	1,50E-05	RARE	MARGINAL	TOLERABLE
DURING MAINTENANCE, DURING USE OF THE VEHICLE IF THERE IS A MALFUNCTION OR DURING BATTERY SWAP	NOT GIVEN	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE	7,50E-06	RARE	MARGINAL	TOLERABLE
DURING MAINTENANCE, DURING USE OF THE VEHICLE IF THERE IS A MALFUNCTION OR DURING BATTERY SWAP	NOT GIVEN	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE	7,50E-06	RARE	MARGINAL	TOLERABLE

2.4.3.2 Centring pins

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
CENTRING PINS	GIVE THE BATTERY STABILITY BY KEEPING IT IN GOOD CONTACT WITH SENSORS AND POWER CONNECTORS	MICROCAR IN USE OR MAINTENANCE	2,00E-07	100%	STOP SUPPORTING THE BATTERY ADEQUATELY	MECHANICAL SHOCK OR INADEQUATE MAINTENANCE

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
THERE IS NO MECHANICAL SUPPORT AND THERE MAY BE POSSIBLE DAMAGE TO THE CONNECTORS AND BATTERIES	THE BATTERY MAY BECOME DISCONNECTED AND DAMAGED FOT THE WHOLE SYSTEM	TO BE DEFINED	TO BE DEFINED	DURING MAINTENANCE, DURING USE OF THE VEHICLE IF THERE IS A MALFUNCTION OR DURING BATTERY SWAP	NOT GIVEN

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
THE CASE ALLOWS THE BATTERY TO REMAIN SOLIDLY IN PLACE	2,00E-07	IMPROBABLE	MARGINAL	NEGLIGIBLE

2.4.3.3 Power connectors

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
POWER CONNECTORS	SAFE CONNECTION AND PLUG-IN BETWEEN BATTERIES AND CABLES	MICROCAR IN USE OR MAINTENANCE	3,00E-06	100%	STOP TRANSMITTING ELECTRICITY	MECHANICAL SHOCK OR SHORT CIRCUIT

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
NO POWER TRANSMISSION FROM THE BATTERIES	THE MOTOR DOES NOT RECEIVE POWER AND THE SYSTEM DOES NOT FUNCTION	TO BE DEFINED	TO BE DEFINED	DURING THE USE OF THE VEHICLE OR THROUGH A SENSOR ALERT	NOT GIVEN

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
NO MITIGATION	3,00E-06	RARE	MARGINAL	TOLERABLE

2.4.3.4 Battery power sensors

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
BATTERY POWER SENSORS	MONITOR THE CORRECT FUNCTIONING AND STATUS OF CHARGE OF THE BATTERY	ALL	5,00E-06	33%	CHARGE DETECTION SENSORS PROVIDE FALSE POSITIVES	INTERNAL SENSOR FAILURE
		ALL	5,00E-06	33%	CHARGE DETECTION SENSORS PROVIDE FALSE NEGATIVES	INTERNAL SENSOR FAILURE
		ALL	5,00E-06	34%	SENSORS DO NOT PROVIDE SIGNALS	SENSORS DAMAGE

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection
IT IS SIGNALED A CHARGE STATUS LOWER THAN THE REAL ONE	NO EFFECT ON THE SYSTEM	TO BE DEFINED	TO BE DEFINED	VEHICLE DIAGNOSTICS
IT IS SIGNALED A CHARGE STATUS HIGHER THAN THE REAL ONE	NO EFFECT ON THE SYSTEM	TO BE DEFINED	TO BE DEFINED	VEHICLE DIAGNOSTICS
NO SIGNAL FLOW INTO THE BATTERY MANAGEMENT SYSTEM	THE SYSTEM DOES NOT DETECT THE BATTERY STATUS	TO BE DEFINED	TO BE DEFINED	VEHICLE DIAGNOSTICS

Maintenance	Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
NOT GIVEN	DIAGNOSTIC REDUNDANCY	1,65E-06	RARE	INSIGNIFICANT	NEGLIGIBLE
NOT GIVEN	DIAGNOSTIC REDUNDANCY	1,65E-06	RARE	INSIGNIFICANT	NEGLIGIBLE
NOT GIVEN	DIAGNOSTIC REDUNDANCY	1,70E-06	RARE	INSIGNIFICANT	NEGLIGIBLE

2.4.3.5 Temperature sensors

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
TEMPERATURE SENSORS	MONITOR THE CORRECT FUNCTIONING AND STATUS TEMPERATURE OF THE BATTERY	ALL	5,00E-06	33%	TEMPERATURE SENSORS PROVIDE FALSE NEGATIVES	INTERNAL SENSOR FAILURE
		ALL	5,00E-06	33%	TEMPERATURE SENSORS PROVIDE FALSE POSITIVES	INTERNAL SENSOR FAILURE
		ALL	5,00E-06	34%	TEMPERATURE SENSORS DO NOT PROVIDE SIGNALS	SENSOR DAMAGE

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
THE SENSOR DETECTS A TEMPERATURE LOWER THAN THE REAL ONE	BATTERY OVERHEATING RISK	TO BE DEFINED	TO BE DEFINED	DURING THE MAINTENANCE	NOT GIVEN
THE SENSOR SIGNALS AN HIGHER TEMPERATURE THAN THE REAL ONE	NO EFFECT ON THE SYSTEM, BUT THERE IS THE BLOCKING OF A BATTERY IF THE REPORTED TEMPERATURE IS TOO HIGH.	TO BE DEFINED	TO BE DEFINED	DURING THE MAINTENANCE	NOT GIVEN
NO SIGNAL FLOW INTO THE BATTERY MANAGEMENT SYSTEM	THE SYSTEM DOES NOT DETECT THE BATTERY STATUS	TO BE DEFINED	TO BE DEFINED	VEHICLE DIAGNOSTICS	NOT GIVEN

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
NO MITIGATION	1,65E-06	RARE	MARGINAL	TOLERABLE
NO MITIGATION	1,65E-06	RARE	INSIGNIFICANT	NEGLIGIBLE
DIAGNOSTICS	1,70E-06	RARE	INSIGNIFICANT	NEGLIGIBLE

2.4.3.6 Internal screws

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
INTERNAL SCREWS	KEEP CENTRING PINS, CONNECTORS AND SENSORS FIRMLY IN PLACE	MICROCAR IN USE OR MAINTENANCE	2,00E-07	100%	SCREW FAILURE	BAD MAINTENANCE OR SHOCK & VIBRATION

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
POSSIBLE DAMAGE TO CONNECTORS, BATTERIES AND CABLES	THE BATTERY PACK IS MECHANICALLY DAMAGED AND THE SYSTEM OPERATION MAY BE DAMAGED	TO BE DEFINED	TO BE DEFINED	DURING THE USE OF THE VEHICLE IF THERE IS A MALFUNCTION OR AN ALERT	NOT GIVEN

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
THE CASE ALLOWS THE BATTERY TO REMAIN SOLIDLY IN PLACE	2,00E-07	IMPROBABLE	MARGINAL	NEGLIGIBLE

2.4.3.7 Sensor cables

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
SENSOR CABLES	TRANSFER SIGNALS FROM THE SENSORS TO THE BATTERY MANAGEMENT SYSTEM	MICROCAR IN USE OR MAINTENANCE	3,00E-06	100%	DO NOT CARRY SIGNAL	TOTAL/PARTIAL CABLE DAMAGE OR BAD MAINTENANCE

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
NO SIGNAL FLOW INTO THE BATTERY MANAGEMENT SYSTEM	THE SYSTEM DOES NOT DETECT THE BATTERY STATUS	TO BE DEFINED	TO BE DEFINED	DIAGNOSTICS AND MAINTENANCE	NOT GIVEN

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
DIAGNOSTIC REDUNDANCY	3,00E-06	RARE	MARGINAL	TOLERABLE

2.4.3.8 Power cables

Component Name	Component Function	Operation mode	Component failure rate (10^-6)	Failure mode percentage (%)	Failure Mode	Failure Cause
POWER CABLES	TRANSFER ELECTRICAL ENERGY FROM THE POWER CONNECTOR TO THE CONVERTER	MICROCAR IN USE OR MAINTENANCE	4,00E-06	90%	THE CABLE IS BROKEN OR BURNED	TOTAL/PARTIAL CABLE DAMAGE OR BAD MAINTENANCE
		MICROCAR IN USE OR MAINTENANCE	4,00E-06	10%	THE CABLE MAKES CONTACT WITH THE CASE	SHEATH USURY

Local effects	System effects	Vehicle effects (Reliability)	Vehicle effects (Safety)	Detection	Maintenance
THE CABLE DOES NOT CARRY ELECTRICITY	I DON'T HAVE ELECTRIC POWER IN/OUT FROM THE SYSTEM	TO BE DEFINED	TO BE DEFINED	DURING THE USE OF THE VEHICLE OR BATTERIES SWAP	EVERY 6 MONTHS OR 5000 km
THE CABLE IS NO LONGER ISOLATED FROM THE REST OF THE SYSTEM	THE CASE COULD GIVE ELECTRIC SHOCK AND THE OPERATOR COULD TAKE THE SHOCK	TO BE DEFINED	TO BE DEFINED	DURING VEHICLE USAGE THE POWER SENSORS DETECT IT	EVERY 6 MONTHS OR 5000 km

Mitigation	Failure mode failure rate (10^-6)	Frequency	Severity	Criticality
NO MITIGATION	3,60E-06	RARE	MARGINAL	TOLERABLE
THE CASE HAS A GROUNDING THAT DISCHARGES POSSIBLE VOLTAGES, ALSO THE TECHNICIANS MUST USE PROTECTIONS DURING THE SWAP	4,00E-07	IMPROBABLE	CRITICAL	TOLERABLE

2.4.4 Reliability Block Diagram

In the Reliability Block Diagram is explained the type of link between the components and how these connections can affect the overall failure rates of the power system (red) and the sensors system (green).

In the following lines there is the legend by which the component diagram:

- R1: Battery Management System;
- R2: Battery;
- R3: Motor;
- R4: Converter;
- R5: Power connector;
- R6: Battery control sensor;
- R7: Power cable;
- R8: Sensor cable.

In terms of the sensor system, it is important to specify that there are multiple sensors for each conduction line. They detect more than one parameter, for example, temperature and battery state of charge are two of them. For simplicity they have been grouped in the single element R6.

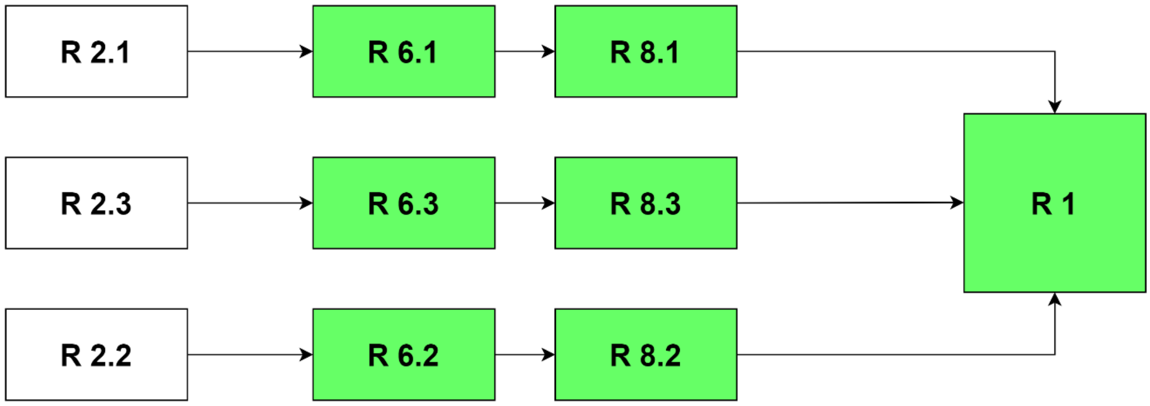


Figure 28 Sensors path

In order to have an index of the reliability, the overall failure rate of the sensor system is calculated. The data used are the individual component failure rates obtained in the FMECA.

The first step is to calculate the failure rate for each branch, since the values for each of the three branches are equal just calculate one:

$$R\ 2.1 * R\ 6.1 * R\ 8.1 = R\ 2.2 * R\ 6.2 * R\ 8.2 = R\ 2.3 * R\ 6.3 * R\ 8.3$$

Substituting the number the result is:

$$3 * 10^{-5} * \ 5 * \ 10^{-6} * \ 3 \ * \ 10^{-6} = 4.5 * 10^{-16}$$

The next step is to calculate the total failure rate. Knowing the failure rate of each sensor branch the result will be as follows:

$$[1 - (1 - R\ 2,6,8)^3] * R1$$

When calculating the failure rate on parallel elements, it is always good to ask how many X elements/branches of the Y parallel elements/branches of the system must operate for the system to work. In this case 1 out of 3 is enough and the formula used is the following $1 - (1-R)^3$.

The value of Battery Management System is not given and for this reason R1 is not transformed in a quantitative value.

Substituting the number the result is:

$$[1-(1-4.5*10^{-16})^3]*R1=0$$

The failure rate of the sensory system is approximately 0.

The power system of electric current is entirely in series, so it is easy to calculate it with the following formula:

$$R\,7.1*R\,5.1*R\,2.1*R\,5.2*R\,7.2*R\,5.3*R\,2.2*R\,5.4*R\,7.3*R\,5.5*R\,2.3*R\,5.6*R\,7.4*R\,4*R\,3=Rtot$$

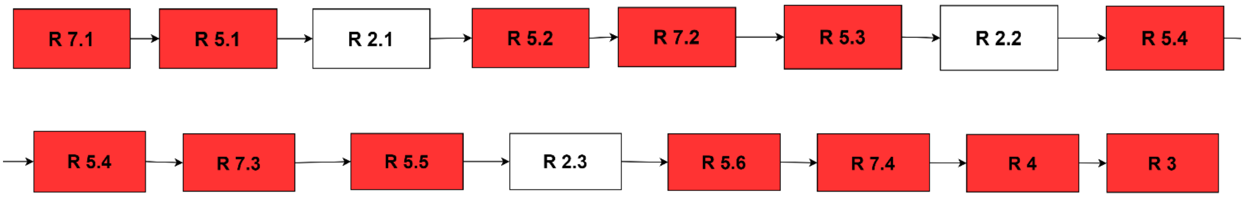


Figure 29 Electric current path

The values of the converter and of the motor are not given and for this reason R4 and R3 are not transformed in quantitative values.

$$4*10^{-6}*3*10^{-6}*3*10^{-5}*3*10^{-6}*4*10^{-6}*3*10^{-6}*3*10^{-5}*3*10^{-6}*4*10^{-6}*3*10^{-6}*3*10^{-5}*3*10^{-6}*4*10^{-6}*R\,4*R\,3=5.038848*10^{-69}*R\,3*R\,4$$

Chapter 3 - Results

This chapter presents the output results of the identification and qualitative analysis phases of the project and process.

A strong assumption that was made in performing the analysis is that all the activities have the same weight in the project. In the proposed excel model it is sufficient to add the cost of each unit to calculate the EMV (estimated monetary value).

In the first graph all risks are represented in terms of their influence on the project, i.e. how much each risk can influence the whole project in percentage terms.

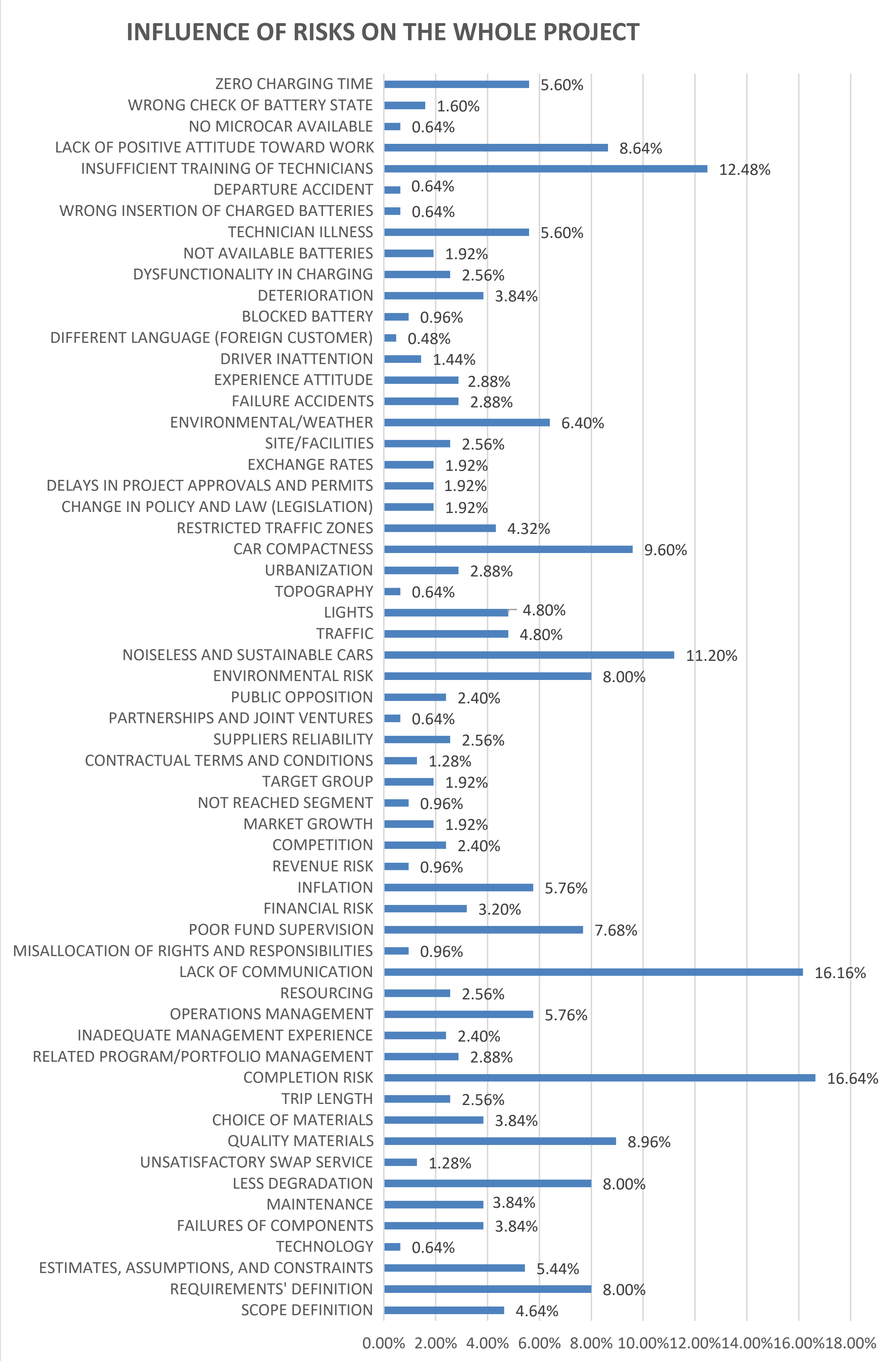
The analysis shows that the risks with the highest percentages are:

- Completion risk (16,64%);
- Lack of communication (16,16%).

These are the risks with the highest incidence not because of the probability and impact values, but for the number of times they are involved in WBS work package activities.

The risks with the lowest impact include:

- Different language (0,48%);
- No microcar available (0.64%);
- Departure accident (0,64%);
- Wrong insertion of charged batteries (0,64%);
- Partnerships & Joint ventures (0,64%);
- Technology (0,64%);


INFLUENCE OF RISKS ON THE WHOLE PROJECT
ZERO CHARGING TIME
5.60%
WRONG CHECK OF BATTERY STATE
1.60%
NO MICROCAR AVAILABLE
0.64%
LACK OF POSITIVE ATTITUDE TOWARD WORK
8.64%
INSUFFICIENT TRAINING OF TECHNICIANS
12.48%
DEPARTURE ACCIDENT
0.64%
WRONG INSERTION OF CHARGED BATTERIES
0.64%
TECHNICIAN ILLNESS
5.60%
NOT AVAILABLE BATTERIES
1.92%
DYSFUNCTIONALITY IN CHARGING
2.56%
DETERIORATION
3.84%
BLOCKED BATTERY
0.96%
DIFFERENT LANGUAGE (FOREIGN CUSTOMER)
0.48%
DRIVER INATTENTION
1.44%
EXPERIENCE ATTITUDE
2.88%
FAILURE ACCIDENTS
2.88%
ENVIRONMENTAL/WEATHER
6.40%
SITE/FACILITIES
2.56%
EXCHANGE RATES
1.92%
DELAYS IN PROJECT APPROVALS AND PERMITS
1.92%
CHANGE IN POLICY AND LAW (LEGISLATION)
1.92%
RESTRICTED TRAFFIC ZONES
4.32%
CAR COMPACTNESS
9.60%
URBANIZATION
2.88%
TOPOGRAPHY
0.64%
LIGHTS
4.80%
TRAFFIC
4.80%
NOISELESS AND SUSTAINABLE CARS
11.20%
ENVIRONMENTAL RISK
8.00%
PUBLIC OPPOSITION
2.40%
PARTNERSHIPS AND JOINT VENTURES
0.64%
SUPPLIERS RELIABILITY
2.56%
CONTRACTUAL TERMS AND CONDITIONS
1.28%
TARGET GROUP
1.92%
NOT REACHED SEGMENT
0.96%
MARKET GROWTH
1.92%
COMPETITION
2.40%
REVENUE RISK
0.96%
INFLATION
5.76%
FINANCIAL RISK
3.20%
POOR FUND SUPERVISION
7.68%
MISALLOCATION OF RIGHTS AND RESPONSIBILITIES
0.96%
LACK OF COMMUNICATION
16.16%
RESOURCING
2.56%
OPERATIONS MANAGEMENT
5.76%
INADEQUATE MANAGEMENT EXPERIENCE
2.40%
RELATED PROGRAM/PORTFOLIO MANAGEMENT
2.88%
COMPLETION RISK
16.64%
TRIP LENGTH
2.56%
CHOICE OF MATERIALS
3.84%
QUALITY MATERIALS
8.96%
UNSATISFACTORY SWAP SERVICE
1.28%
LESS DEGRADATION
8.00%
MAINTENANCE
3.84%
FAILURES OF COMPONENTS
3.84%
TECHNOLOGY
0.64%
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS
5.44%
REQUIREMENTS' DEFINITION
8.00%
SCOPE DEFINITION
4.64%
0.00%
2.00%
4.00%
6.00%
8.00%
10.00%
12.00%
14.00%
16.00%
18.00%

Graph 1 Influence of risks on the entire project

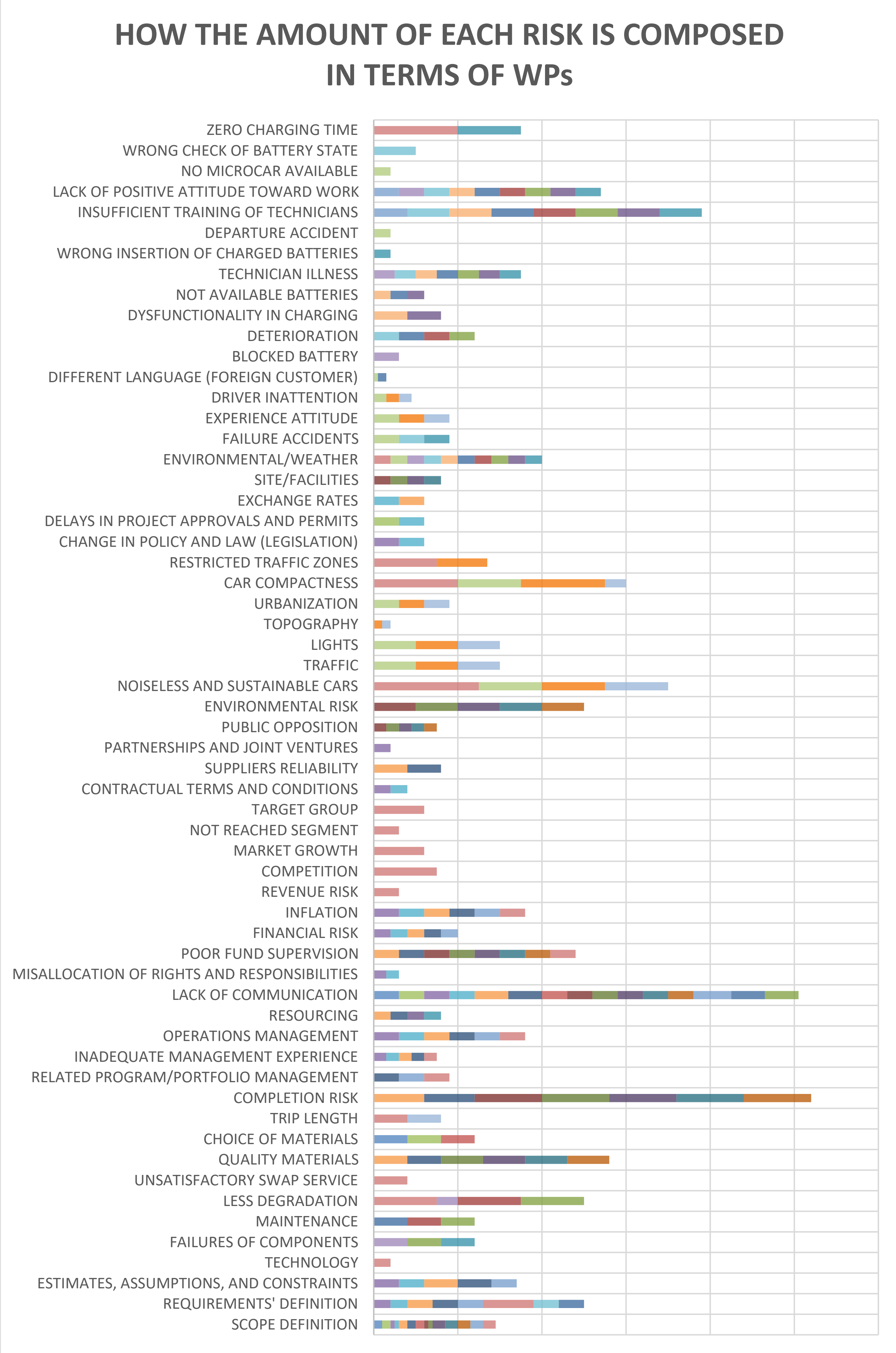
In the second graph a study was made on how WPs influence each risk, so that it can be seen graphically how heterogeneous a risk is in this sense.

For example, there are risks like "Scope definition", which influences many WPs but it is not particularly relevant. Other risks with a positive impact on the project (opportunities), on the other hand, have relevance even if they do not influence many activities, such as:

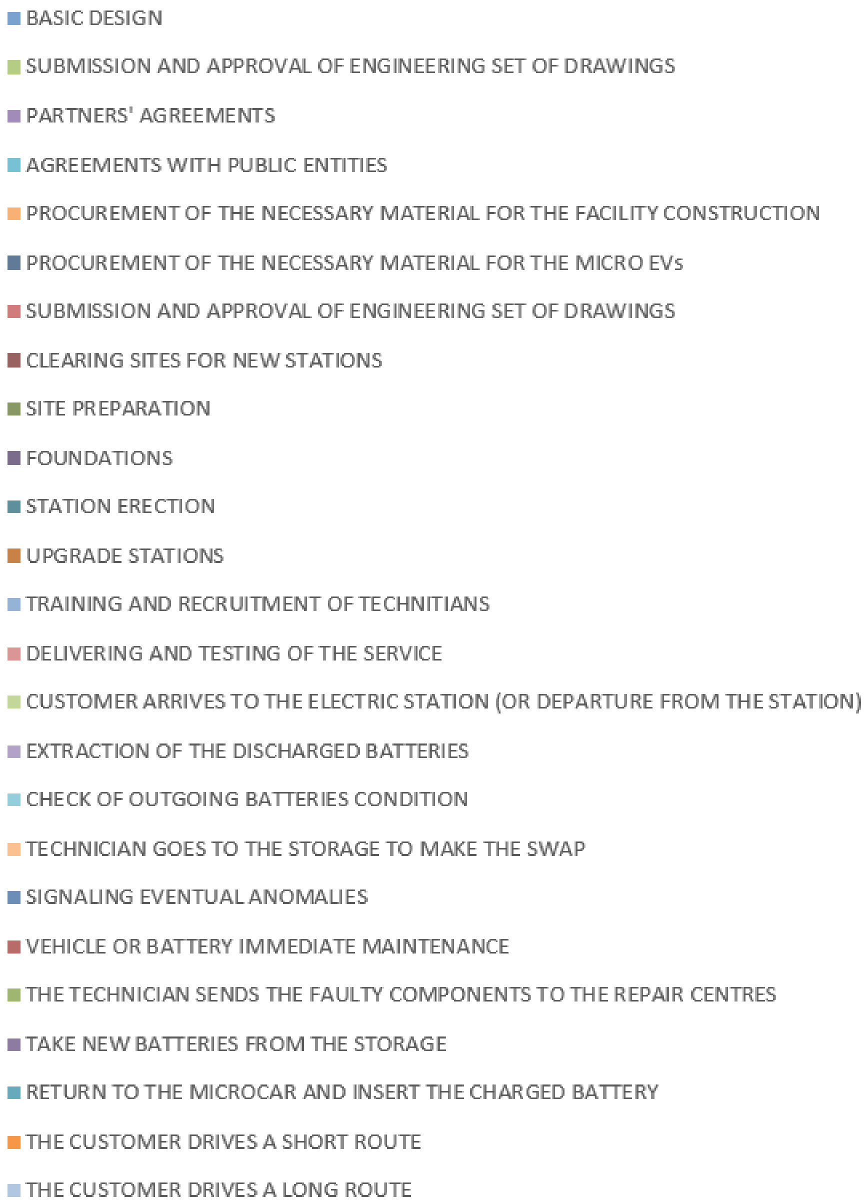
- Zero charging time;
- Noiseless and sustainable cars;
- Less degradation;

There are also several minor risks affecting a single WP, for example:

- Wrong check of battery state;
- No microcar available;
- Departure accident;
- Target group;
- Not reached segment;
- Market growth;
- Competition;
- Reventue risk;
- etc.


HOW THE AMOUNT OF EACH RISK IS COMPOSED IN TERMS OF WPs
ZERO CHARGING TIME
WRONG CHECK OF BATTERY STATE
NO MICROCAR AVAILABLE
LACK OF POSITIVE ATTITUDE TOWARD WORK
INSUFFICIENT TRAINING OF TECHNICIANS
DEPARTURE ACCIDENT
WRONG INSERTION OF CHARGED BATTERIES
TECHNICIAN ILLNESS
NOT AVAILABLE BATTERIES
DYSFUNCTIONALITY IN CHARGING
DETERIORATION
BLOCKED BATTERY
DIFFERENT LANGUAGE (FOREIGN CUSTOMER)
DRIVER INATTENTION
EXPERIENCE ATTITUDE
FAILURE ACCIDENTS
ENVIRONMENTAL/WEATHER
SITE/FACILITIES
EXCHANGE RATES
DELAYS IN PROJECT APPROVALS AND PERMITS
CHANGE IN POLICY AND LAW (LEGISLATION)
RESTRICTED TRAFFIC ZONES
CAR COMPACTNESS
URBANIZATION
TOPOGRAPHY
LIGHTS
TRAFFIC
NOISELESS AND SUSTAINABLE CARS
ENVIRONMENTAL RISK
PUBLIC OPPOSITION
PARTNERSHIPS AND JOINT VENTURES
SUPPLIERS RELIABILITY
CONTRACTUAL TERMS AND CONDITIONS
TARGET GROUP
NOT REACHED SEGMENT
MARKET GROWTH
COMPETITION
REVENUE RISK
INFLATION
FINANCIAL RISK
POOR FUND SUPERVISION
MISALLOCATION OF RIGHTS AND RESPONSIBILITIES
LACK OF COMMUNICATION
RESOURCING
OPERATIONS MANAGEMENT
INADEQUATE MANAGEMENT EXPERIENCE
RELATED PROGRAM/PORTFOLIO MANAGEMENT
COMPLETION RISK
TRIP LENGTH
CHOICE OF MATERIALS
QUALITY MATERIALS
UNSATISFACTORY SWAP SERVICE
LESS DEGRADATION
MAINTENANCE
FAILURES OF COMPONENTS
TECHNOLOGY
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS
REQUIREMENTS' DEFINITION
SCOPE DEFINITION

Graph 2 Risk heterogeneity



For the representation of the third analysis a doughnut graph was chosen, where the weight of each WP on the project is represented.

It can be seen that the one with the highest percentage by far is "Delivering and testing of the service", while those with a lower relative weight are:

- Basic design;
- Detailed engineering;

- Submission and approvals of engineering set of drawings;

This result is due to the fact that in this case the risks associated with the engineering factor are low and related only to the engineering phase.

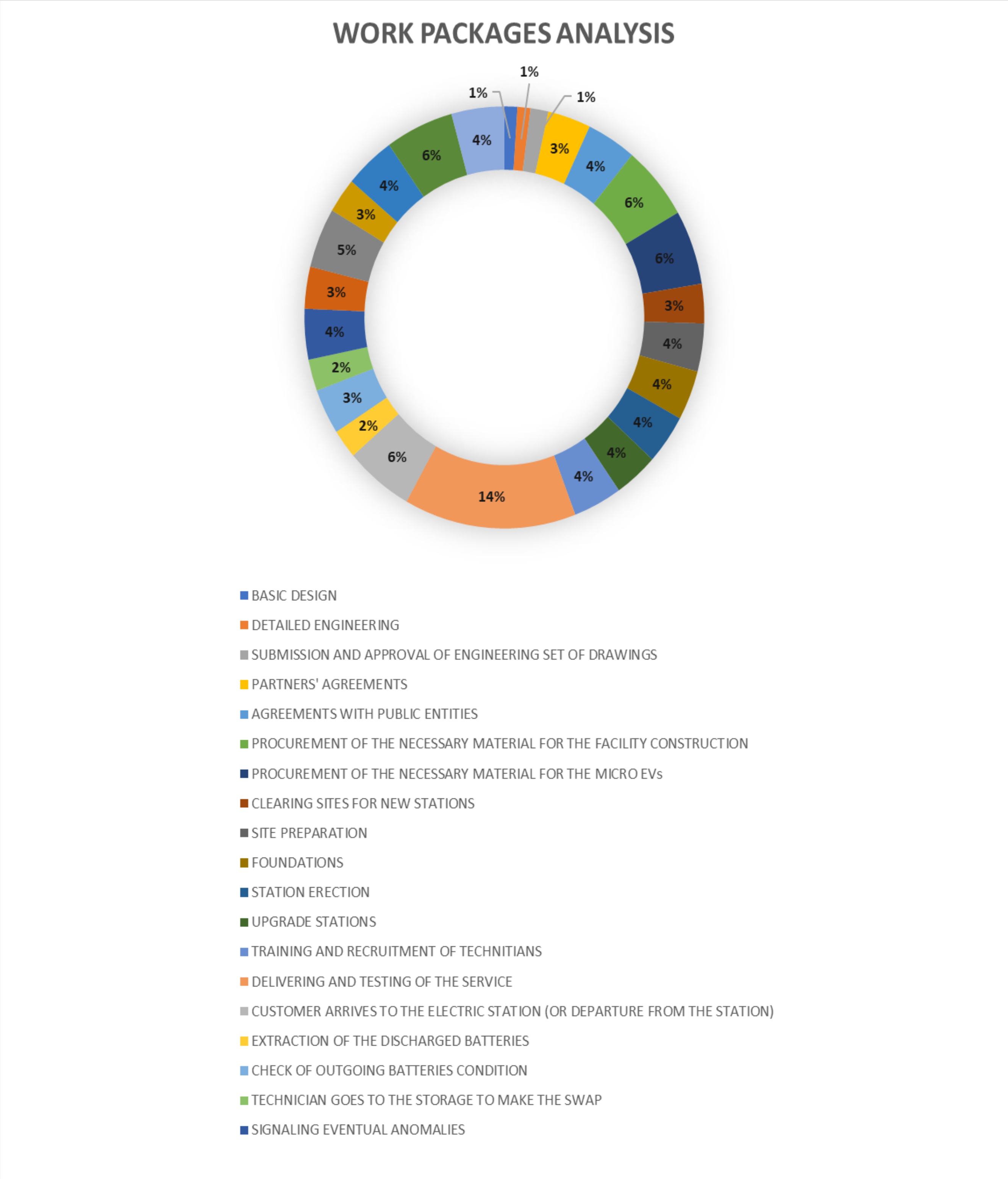


Figure 30 Work packages analysis

3.1 Probability Impact matrix

In this section the Probability and impact matrix technique was applied, where the parameters expressed in Section 1.6 were used for the values expressed on the y-axis and the x-axis. It is important to say that the following analysis, is based on the evaluation of each risk on the activities to which it is linked, and not as previously on all the activities of the project as a whole. In this way, the number of links that a risk has with the WPs of the project or process is not influential.

For simplicity and better understanding of the matrix, the risks have been numbered. The following table shows the correlations between the risks and their ID number.

RISK FACTORS NAME	**RISK FACTORS ID**
SCOPE DEFINITION	R1
REQUIREMENTS' DEFINITION	R2
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS	R3
TECHNOLOGY	R4
FAILURES OF COMPONENTS	R5
MAINTENANCE	R6
LESS DEGRADATION	R7
UNSATISFACTORY SWAP SERVICE	R8
QUALITY MATERIALS	R9
CHOICE OF MATERIALS	R10
TRIP LENGTH	R11
COMPLETION RISK	R12
RELATED PROGRAM/PORTFOLIO MANAGEMENT	R13
INADEQUATE MANAGEMENT EXPERIENCE	R14
OPERATIONS MANAGEMENT	R15
RESOURCING	R16
LACK OF COMMUNICATION	R17
MISALLOCATION OF RIGHTS AND RESPONSIBILITIES	R18
POOR FUND SUPERVISION	R19

FINANCIAL RISK	R20
INFLATION	R21
REVENUE RISK	R22
COMPETITION	R23
MARKET GROWTH	R24
NOT REACHED SEGMENT	R25
TARGET GROUP	R26
CONTRACTUAL TERMS AND CONDITIONS	R27
SUPPLIERS RELIABILITY	R28
PARTNERSHIPS AND JOINT VENTURES	R29
PUBLIC OPPOSITION	R30
ENVIRONMENTAL RISK	R31
NOISELESS AND SUSTAINABLE CARS	R32
TRAFFIC	R33
LIGHTS	R34
TOPOGRAPHY	R35
URBANIZATION	R36
CAR COMPACTNESS	R37
RESTRICTED TRAFFIC ZONES	R38
CHANGE IN POLICY AND LAW (LEGISLATION)	R39
DELAYS IN PROJECT APPROVALS AND PERMITS	R40
EXCHANGE RATES	R41
SITE/FACILITIES	R42
ENVIRONMENTAL/WEATHER	R43
FAILURE ACCIDENTS	R44
EXPERIENCE ATTITUDE	R45
DRIVER INATTENTION	R46
DIFFERENT LANGUAGE (FOREIGN CUSTOMER)	R47
BLOCKED BATTERY	R48
DETERIORATION	R49
DYSFUNCTIONALITY IN CHARGING	R50

NOT AVAILABLE BATTERIES	R51
TECHNICIAN ILLNESS	R52
WRONG INSERTION OF CHARGED BATTERIES	R53
DEPARTURE ACCIDENT	R54
INSUFFICIENT TRAINING OF TECHNICIANS	R55
LACK OF POSITIVE ATTITUDE TOWARD WORK	R56
NO MICROCAR AVAILABLE	R57
WRONG CHECK OF BATTERY STATE	R58
ZERO CHARGING TIME	R59

Table 7 Risks identification code

In the following graph, it can be seen that the risks with the greatest impact on the activities to which they are linked are R32 and R59 above all. They correspond respectively to "Noiseless and sustainable cars" and "Zero charging time". Furthermore, they are both risks with a positive impact on the project, and are therefore considered as opportunities. These two elements are considered together with R37 (Car compactness) the Core business and the strengths of the micro electric car-sharing project.

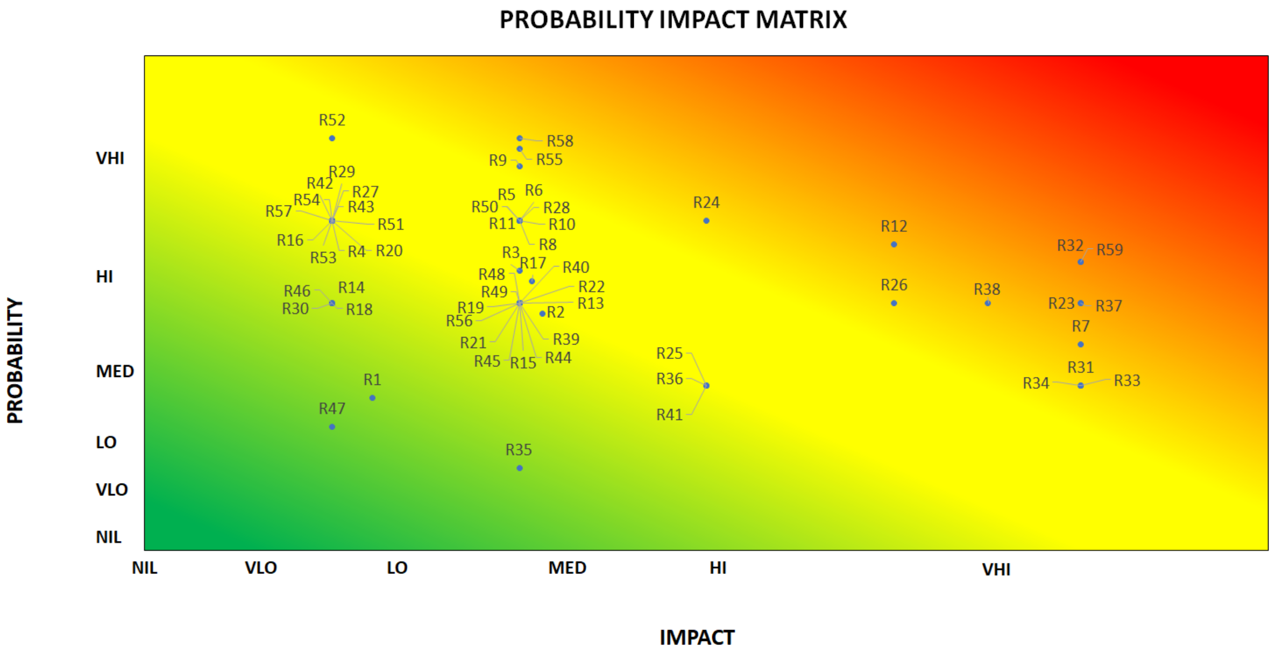


Figure 31 Probability Impact matrix

Other risks that have a relevant level of probability and risk in this respect are:

- R23 (Competition): This risk is only related to the commissioning activity and is significant, but you can see the difference with the first two bar graphs where compared to the whole project it is almost irrelevant (2.4%);
- R12 (Completion risk): This risk is relevant for all analyses since even in the bar graphs this is the risk with the highest weighting on the project (16.64%);
- R38 (Restricted traffic zone) and R7 (Less degradation): These are risks that are considered as opportunities to be exploited as shown by the matrix, while their weight on the whole project is not particularly relevant.

Moving closer to the yellow area of the graph are: R31 (Environmental risk), R33 (Traffic), R34 (Lights), R26 (Target group), R24 (Market growth).

These are risks on which it is certainly necessary to apply strategies because they are high in the contest of the activities in which they are involved , but they are not particularly relevant in the contest of the whole project.

As regard the part concerning component failure modes, it is summarized highlighting the criticality output in the following table:

Component Name	Failure Mode	Criticality
BATTERY	CONNECTOR OXIDATION	TOLERABLE
	STRUCTURAL (MECHANICAL) BATTERY DAMAGE	TOLERABLE
	INTERNAL BATTERY (ELECTRICAL) DAMAGE	TOLERABLE
CENTERING PINS	STOP SUPPORTING THE BATTERY ADEQUATELY	NEGLIGIBLE
POWER CONNECTORS	STOP TRANSMITTING ELECTRICITY	TOLERABLE
BATTERY POWER SENSORS	CHARGE DETECTION SENSORS PROVIDE FALSE POSITIVES	NEGLIGIBLE
	CHARGE DETECTION SENSORS PROVIDE FALSE NEGATIVES	NEGLIGIBLE
	SENSORS DO NOT PROVIDE SIGNALS	NEGLIGIBLE
TEMPERATURE SENSORS	TEMPERATURE SENSORS PROVIDE FALSE NEGATIVES	TOLERABLE
	TEMPERATURE SENSORS PROVIDE FALSE POSITIVES	NEGLIGIBLE
	TEMPERATURE SENSORS DO NOT PROVIDE SIGNALS	NEGLIGIBLE
INTERNAL SCREWS	SCREW FAILURE	NEGLIGIBLE
SENSOR CABLES	DO NOT CARRY SIGNAL	TOLERABLE
POWER CABLES	THE CABLE IS BROKEN OR BURNED	TOLERABLE
	THE CABLE MAKES CONTACT WITH THE CASE	TOLERABLE

Table 8 Failure modes criticality

The analysis performed did not reveal any particularly dangerous failure modes. For the majority of failure modes classified as tolerable, are planned mitigation actions as reported in the FMECA.

Chapter 4 - Conclusions

In the conclusive part of the elaborate are exposed the answer stragies put into effect on the base of the obtained results.

In the following diagram, the risks (threats and opportunities) have been analyzed on the basis of the activities to which they are correlated, in order to understand how to apply the strategies: Accept, Mitigate, Transfer or Avoid.

It is important to underly that for opportunities the meaning of response categories is the inverse, as indicated in the description.

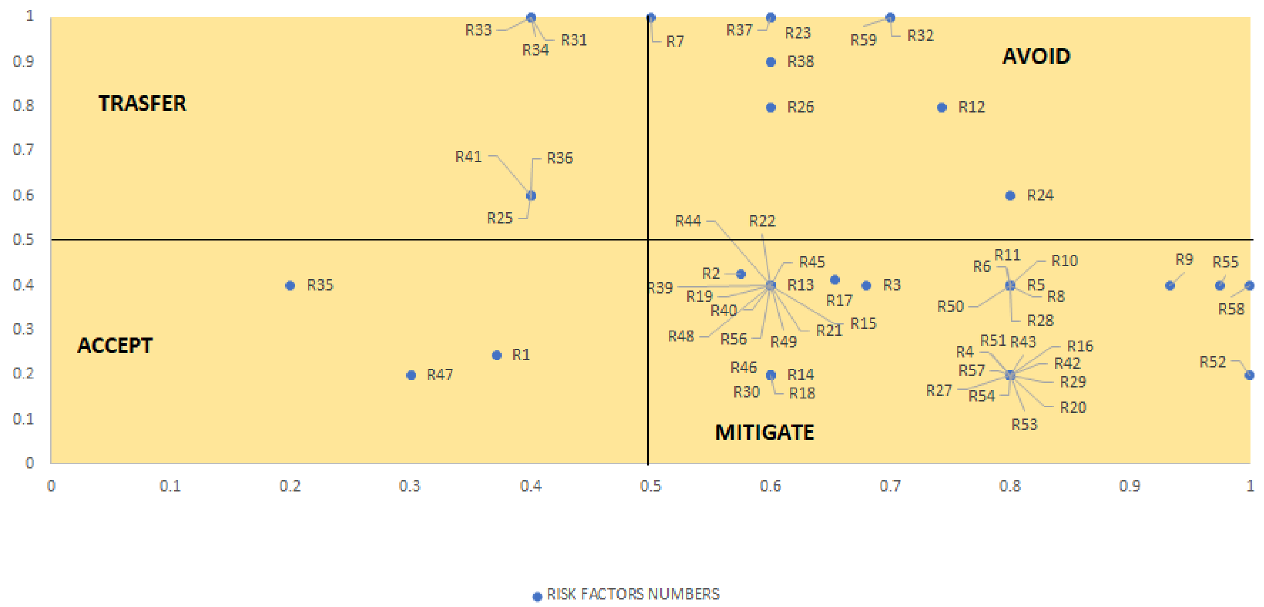


Figure 32 Response Strategies

In the following table are listed the response strategies inherent to the risks indicated through the ID code described in section 3.1.

RISK FACTOR NAME	RISK FACTORS ID	RESPONSE	RESPONSE DESCRIPTION
SCOPE DEFINITION	R1	ACCEPT	This risk can be accepted because it is not high in the activities affected.

REQUIREMENTS' DEFINITION	R2	MITIGATE	This risk can be mitigated finding a deal where the possible changes of requirements are delimited.
ESTIMATES, ASSUMPTIONS, AND CONSTRAINTS	R3	MITIGATE	This risk can be mitigated enhancing the team that make these estimates and making a periodic revision to understand if those foresights are pertinent.
TECHNOLOGY	R4	MITIGATE	This risk is not dangerous now, but it is fundamental to monitor the market trend on micorcars.
FAILURES OF COMPONENTS	R5	MITIGATE	This risk can be mitigated improving the maintenance service in order to minimise the failure components during the usage of customers.
MAINTENANCE	R6	MITIGATE	This risk can be mitigated improving the maintenance service in order to minimise the failure components during the usage of customers and improving the quality of training for maintenance team.
LESS DEGRADATION	R7	AVOID (opportunity)	This risk needs to be exploited using specific materials for electric microcars, because there

			are not others providing this specific service with electric vehicles.
UNSATISFACTORY SWAP SERVICE	R8	MITIGATE	This risk can be mitigated keeping constantly under monitoring the desires of customers, and taking care of service quality.
QUALITY MATERIALS	R9	MITIGATE	This risk can be mitigated putting additional controls in place to check that the materials used are the correct ones.
CHOICE OF MATERIALS	R10	MITIGATE	This risk can be mitigated putting additional controls to check if the choice of materials during Engineering Phase is correct.
TRIP LENGTH	R11	MITIGATE	This risk may be mitigated alerting the customer to change vehicles or to go to the nearest charging station.
COMPLETION RISK	R12	AVOID	This risk should be avoided having the appropriate float for activities on the critical path. It is also necessary to have the right monetary contingencies to accommodate the delay.
RELATED PROGRAM/PORTFOLIO MANAGEMENT	R13	MITIGATE	This risk can be mitigated finding the right balance of correlation to other

			projects.
INADEQUATE MANAGEMENT EXPERIENCE	R14	MITIGATE	This risk can be mitigated by paying particular attention to updating and improving management skills.
OPERATIONS MANAGEMENT	R15	MITIGATE	An effective mitigation action for subsequent operations would be to standardize business operations as much as possible. In the immediately it is appropriate to take advantage of budgeted contingencies and reschedule activities in case of delays.
RESOURCING	R16	MITIGATE	In this case, the mitigation strategy is to acquire scarce resources from third-party entities. If, on the other hand, it is possible to wait until resources are available without using the option of contacting outside firms, new supplies are awaited.
LACK OF COMMUNICATION	R17	MITIGATE	The lack of effective communication (internal and external to the firm) can be mitigated by rescheduling delayed activities or by using contingencies allocated for

			this risk. Therefore, it is fundamental the update of communication technicques.
MISALLOCATION OF RIGHTS AND RESPONSIBILITIES	R18	MITIGATE	The mitigation strategy includes a plan for reviewing commitments, so that work in WBS activities is redefined according to specifications. Project management tools help to ensure these types of risks can decrease in likelihood.
POOR FUND SUPERVISION	R19	MITIGATE	The mitigation strategy for this risk, includes in-depth inspections to understand the reasons for non-alignment on the use of funds and try to recover at least some of them.
FINANCIAL RISK	R20	CONTINGENCY	Application of an appropriate contingency plan for this type of risk.
INFLATION	R21	CONTINGENCY	Application of an appropriate contingency plan for this type of risk.
REVENUE RISK	R22	MITIGATE	This risk can be mitigated by trying to break down all costs related to secondary service functionality in the first few months after commissioning, so that you

			can have a surplus that can cover a lower revenue.
COMPETITION	R23	AVOID	In case other competitors decide to make a battery swap service, it is important to be able to create a new competitive advantage by implementing new strategies. These strategies will be designed on the basis of customer needs that will emerge in the first months of the car-sharing service.
MARKET GROWTH	R24	AVOID (opportunity)	This is a type of opportunity that absolutely must be exploited trying to follow the needs of the market that is constantly growing.
NOT REACHED SEGMENT	R25	TRANSFER	This risk is transferred to stakeholders, who will have to figure out how to serve a market segment like laggards who still have doubts about the service and technologies used.
TARGET GROUP	R26	AVOID (opportunity)	For this risk, it is very important for the company to address the needs of costumers ranging from 16+ to younger workers, as these segments are the ones most often open to

			innovation.
CONTRACTUAL TERMS AND CONDITIONS	R27	MITIGATE	This risk can be mitigated through effective negotiation between the parties involved to establish new guidelines for conditions that were not anticipated during contract development.
SUPPLIERS RELIABILITY	R28	MITIGATE	This risk can be mitigated by secondary suppliers who can make up the shortfall if there are problems with the suppliers.
PARTNERSHIPS AND JOINT VENTURES	R29	MITIGATE (opportunity)	A way to exploit this risk is to have a strong willingness to expand the business to different services reaching a service with multiple strenghts.
PUBLIC OPPOSITION	R30	MITIGATE	This risk can be mitigated finding a compromise with opposed entities to minimise the conflicts.
ENVIRONMENTAL RISK	R31	TRANSFER	This risk is transferred to a stakeholder that take care of this type of aspects and can minimise their impact.
NOISELESS AND SUSTAINABLE CARS	R32	AVOID (opportunity)	This is one of the core characteristics of the microcar used in the project, in fact it is important to

			consider crucial this aspect as a point of strength.
TRAFFIC	R33	TRANSFER	This risk is transferred to a stakeholder that has the duty to provide the customer the route with less traffic during the usage.
LIGHTS	R34	TRANSFER	This risk is transferred to a stakeholder that has the duty to provide the customer the route with less lights considered dangerous during the usage.
TOPOGRAPHY	R35	ACCEPT	The topography risk is accepted.
URBANIZATION	R36	TRANSFER	This risk is transferred to a stakeholder that has the duty to provide the customer an update condition of the streets traveled during the route.
CAR COMPACTNESS	R37	AVOID (opportunity)	This is one of the core characteristics of the microcar used in the project, in fact it is important to consider crucial this aspect as a point of strength.
RESTRICTED TRAFFIC ZONES	R38	AVOID (opportunity)	This risk represents the possibility for the users of the service to enter inside the restricted traffic zones and it is a useful benefit that

			enhance the service quality.
CHANGE IN POLICY AND LAW (LEGISLATION)	R39	MITIGATE	This risk can be mitigated bringing the correct modification to the services provided, with the respect to the change of policies.
DELAYS IN PROJECT APPROVALS AND PERMITS	R40	MITIGATE	This risk can be mitigated allocating the proper float to this activity thanks to a reschedulation of the Gant Chart plan.
EXCHANGE RATES	R41	TRANSFER	This risk can be transferred to the suppliers that should have the care to make the transactions on the right time.
SITE/FACILITIES	R42	MITIGATE	This risk can be mitigated trying to use that type of infrastructure or site for other purposes useful to the project or selling them if it is convenient.
ENVIRONMENTAL/WEATHER	R43	ANTICIPATE / TRANSFER	No mitigation actions in this case, but this risk can be anticipated asking the car manufacturer to take car of this aspect.
FAILURE ACCIDENTS	R44	MITIGATE	The mitigation action is given by the maintenace service provided at the recharge station by the technitian.

EXPERIENCE ATTITUDE	R45	MITIGATE	This risk can be mitigated thanks to the sensors of the micorcar that can signal eventual dangers.
DRIVER INATTENTION	R46	MITIGATE	This risk can be mitigated thanks to the sensors of the micorcar that can signal eventual dangers.
DIFFERENT LANGUAGE (FOREIGN CUSTOMER)	R47	ACCEPT	The risk that the customer and the technitian are not able to communicate due to different languages is very unlikely and don't affect particularly the service.
BLOCKED BATTERY	R48	MITIGATE	In the case the battery is blocked the customer can simply change the micro-car.
DETERIORATION	R49	MITIGATE	In the case the battery is blocked the customer can simply change the micro-car.
DYSFUNCTIONALITY IN CHARGING	R50	MITIGATE	For this risk, the mitigation passes through the sensors that should signal immediately that the battery taken is not charged.
NOT AVAILABLE BATTERIES	R51	MITIGATE	The mitigation action is to send the customer to the nearest recharge station to make the swap on the

			microcar or making the customer wait for the recharge of the first available battery.
TECHNICIAN ILLNESS	R52	MITIGATE	The risk can be mitigated with the help of another available technician who can substitute him/her.
WRONG INSERTION OF CHARGED BATTERIES	R53	MITIGATE	This risk can be mitigated with the signal of the sensors that detect the mulfanction.
DEPARTURE ACCIDENT	R54	MITIGATE	The departure accident can be mitigated with a specific layout of the recharge station. The most delicate elements are put lantons from the customer's transit.
INSUFFICIENT TRAINING OF TECHNICIANS	R55	MITIGATE	Mitigation of this risk is covered by the sensors' running that indicate if the technician has not performed all actions correctly.
LACK OF POSITIVE ATTITUDE TOWARD WORK	R56	MITIGATE	Mitigation of this risk is covered by the sensors' running that indicate if the technician has not performed all actions correctly.
NO MICROCAR AVAILABLE	R57	MITIGATE	This risk can be mitigated by waiting for the battery

			change of the microcar in use at that time by the customer.
WRONG CHECK OF BATTERY STATE	R58	MITIGATE	Mitigation of this risk should be covered by the sensors' running that indicate if the technician has not performed all actions correctly.
ZERO CHARGING TIME	R59	AVOID (opportunity)	This is the most important and unicque feature of the car-sharing project which makes the service offered truly innovative.

Table 9 Mitigation table

It is important to report possible response strategies for each risk to offer a possible solution on how to deal with the risk to managers working in the area of competence.

Considering also the weight of risks on the whole project, the response strategy is mainly focused on risks such as: Completion risk, Lack of communication, Noiseless and sustainable cars, Insufficient training of technicians.

These are the risks that have a percentage of risk greater than 10% on the whole project, therefore, they would deserve greater attention than others.

The part of the component failures, as already performed in the previous chapter, it does not detect dangerous failures but at the most tolerable ones. For each of the failure modes have been proposed a mitigation action when possible.

Component Name	Failure Mode	Mitigation
BATTERY	CONNECTOR OXIDATION	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE
	STRUCTURAL (MECHANICAL) BATTERY DAMAGE	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE
	INTERNAL BATTERY (ELECTRICAL) DAMAGE	THE SENSORS SIGNAL THE CHANGE IN POWER AND MAINTENANCE IS DONE
CENTERING PINS	STOP SUPPORTING THE BATTERY ADEQUATELY	THE CASE ALLOWS THE BATTERY TO REMAIN SOLIDLY IN PLACE
POWER CONNECTORS	STOP TRANSMITTING ELECTRICITY	NO MITIGATION
BATTERY POWER SENSORS	CHARGE DETECTION SENSORS PROVIDE FALSE POSITIVES	DIAGNOSTIC REDUNDANCY
	CHARGE DETECTION SENSORS PROVIDE FALSE NEGATIVES	DIAGNOSTIC REDUNDANCY
	SENSORS DO NOT PROVIDE SIGNALS	DIAGNOSTIC REDUNDANCY
TEMPERATURE SENSORS	TEMPERATURE SENSORS PROVIDE FALSE NEGATIVES	NO MITIGATION
	TEMPERATURE SENSORS PROVIDE FALSE POSITIVES	NO MITIGATION
	TEMPERATURE SENSORS DO NOT PROVIDE SIGNALS	DIAGNOSTICS
INTERNAL SCREWS	SCREW FAILURE	THE CASE ALLOWS THE BATTERY TO REMAIN SOLIDLY IN PLACE
SENSOR CABLES	DO NOT CARRY SIGNAL	DIAGNOSTIC REDUNDANCY
POWER CABLES	THE CABLE IS BROKEN OR BURNED	NO MITIGATION
	THE CABLE MAKES CONTACT WITH THE CASE	THE CASE HAS A GROUNDING THAT DISCHARGES POSSIBLE VOLTAGES, ALSO THE TECHNICIANS MUST USE PROTECTIONS DURING THE SWAP

Table 10 Failure modes mitigation table

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