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Maintenance engineering and KPIs applied to electric and ICE vehicles operating in the urban hygiene context

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Abstract

The thesis is done in cooperation with IREN Ambiente, a business unit part of the IREN S.P.A group.

IREN Ambiente (or IAm) is the society of the group that coordinates and manage the urban hygiene, the integrated waste cycle and the renewable energy systems controlling also more than 30 plants for the waste treatment.

The management of the urban hygiene and the waste collection is performed for the city of Torino, Vercelli and her 26 municipalities, for 119 municipalities present in Emilia Romagna in the provinces of Parma, Piacenza and Reggio Emilia, La Spezia and Vercelli while the services are performed for a total of 2,9 millions of inhabitants.

This document will cover different topics related with maintenance engineering, KPIs and instructions on how to improve workshops efficiency reporting a case study for the sweepers owned by IREN Ambiente.

The use of SAP PM and SAP WASTE for the creation of reports useful to the analysis of KPIs will be developed and improvements in terms of predictive maintenance processes will be analyzed and suggested.

The results obtained for the case study demonstrate that corrective maintenance processes account for most of the maintenance actions with more than 90% of the operations and the 84,4% of the total maintenance costs. Every year more than 10% of the initial investment costs for sweepers is spent on maintenance processes where the costs for preventive interventions account for less than 1%.

Use of electric vehicles applied in the urban sanitation context and a calculation of the energy needs to charge the vehicles that are planned to be acquired in 2030 following the industrial plan of the business unit are also performed.

The power estimated to be installed in AMIAT, society part of IAm operating for the city of Turin, is computed also knowing the electric vehicles already present that will be substituted until 2030 because of aging. The calculations are performed for both AC charging and AC/DC charging when the vehicles are projected to be charged also in DC. The results express that more than 4MW are needed for the simultaneous charging in AC for all the working centers and more than 15 MW in DC.

For all the working centers part of AMIAT the amounts of power that will need to be installed until 2030 are computed with details for each year.

At the end of the thesis, knowing that in IREN Ambiente the depreciation period for vehicles is around 8 years, an analysis on how to manage the Li-ion batteries to preserve them from aging is reported focusing also on the effects of DC charging on electric vehicles.

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Nomenclature and abbreviations:

AF	Active fleet
ANF	Annual number of failures
AOT	Annual operating time
BMS	Battery Management system
CBM	Condition-based maintenance
CC-CV	Constant current – Constant voltage charging strategy
CCM	Cost of the corrective maintenance processes
CCS	Combined Charging System
CDC	Center cost
CEM	Cost of the extraordinary maintenance processes
CIP	Contribution of internal personnel cost
CIPC	Contribution of indirect personnel costs
CM	Corrective maintenance
CMO	Contribution of maintenance on output
CPM	Cost of the corrective maintenance processes
CSPM	Contribution of spare parts and material cost
CTPM	Total cost of the specific maintenance processes
CTT	Cost for the interventions performed by third parties
DISP OGIN	Inactive item
DoD	Depth of discharge
DTCB	Down-time due to condition-based maintenance processes
DTCM	Down-time due to corrective maintenance processes
DTIM	Down-time due to improvement maintenance processes
DTPM	Down-time due to predetermined maintenance processes
DTPMV	Down-time due to preventive maintenance processes
EQSU	Equipment mounted on a vehicle
EV	Electric Vehicles
F	Faraday's constant
FCAN	Cancelled item
I	Current
IAm	IREN Ambiente
IM	Improvement maintenance
IMPC	Internal maintenance personnel cost
IPC	Total indirect personnel cost
IW21	Transition code used in SAP PM to create warning
IW22	Transition code used in SAP PM to modify an existing warning
IW23	Transition code used in SAP PM to visualize an existing order
IW28	Transition code used in SAP PM to modify a report of warnings
IW29	Transition code used in SAP PM to visualize a report of warning
IW31	Transition code used in SAP PM to create a maintenance order
IW32	Transition code used in SAP PM to modify an existing maintenance order

IW33	Transition code used in SAP PM to visualize an existing maintenance order
IW38	Transition code used in SAP PM to modify a report of orders
IW39	Transition code used in SAP PM to visualize a report of orders
KPI	Key performance indicator
LAM	Loss of active material
LCO	Lithium cobalt oxide
LIB	Lithium-ion battery
LLI	Loss of lithium inventory
LMO	Lithium-ion manganese oxide battery
MCC	Multistage constant current protocol
MCI	Maintenance contribution related to investments
MONT	Vehicle assigned to a technical headquarter
MRT	Mean time to repair
MTBF	Meantime between failures
MU	Total costs of material and consumables
n	Number of electrons involved in the reactions
NCA	Lithium nickel cobalt aluminum oxide
NMC	Lithium nickel manganese cobalt oxide
NRES	Not scheduled disposal order due to errors
OBC	On-board computer
ODM	Serial maintenance order number
OEE	Overall equipment effectiveness
OI	Internal order
PARV	Physical asset replacement values
PCC	Pulse charging protocols
PCM	Phase change material
PDCA	Plan, Do, Act and Check
PM	Predetermined maintenance
PMV	Preventive maintenance
PTO	Power take-off
Q_{irr}	Irreversible heat produced
q_{neg}	Negative electrode capacity
q_{pos}	Positive electrode capacity
QO	Quantity of output
R	Cell resistance
RDM	Warehouse request
RMC	Relative maintenance costs
ROF	Rate of failures
ΔS	Entropy changes during reactions
SAP	Systems applications and products in data processing
SAP PM	SAP plaint maintenance
SAP WASTE	SAP module for scheduling services
SCHD	Scheduled disposal order
SCPZ	Partially scheduled disposal order
SEI	Solid electrolyte interphase

SoC	State-of-Charge
SoF	State-of-Function
SoH	State-of-Health
SoS	State-of-Safety
S_{neg}	Scale factor for the negative electrode
S_{pos}	Scale factor for the positive electrode
T	Absolute temperature
TCSP	Total costs of spare parts
TDT	Total down-time due to maintenance reasons
TMC	Total maintenance costs
TNAM	Time in which the item is not available due to maintenance
TNF	Total number of failures
TOT	Total operating time
TPMI	Costs for task performed by maintenance for investments
TTA	Total availability time
TTR	Total time to repair
TTR	Total time to repair
UCM	Unavailability cost due to maintenance
V_{batt}	Cell voltage
VCP	Variable current profiles
WBS	Work breakdown structure
WLTC	Worldwide harmonized light vehicles test cycle
ZJI1	Corrective maintenance order
ZJI2	Cyclic preventive maintenance order
ZJI3	Extraordinary maintenance order
ZP	Preventive maintenance warning
ZR	Corrective maintenance warning
ZS	Extraordinary maintenance warning
ZWA_PIANIFICAZIONE	Transition code used in SAP WASTE to schedule the services

1. Maintenance engineering and KPIs

1.1 Maintenance engineering, definitions and basic concepts

In the maintenance engineering field, maintenance plays an important role in terms of technical, administrative and managerial actions done during the life cycle of an item intended to retain it in, restore it to, a state in which it can perform the required function. [1]

Technical maintenance actions include observation and analysis of the item state (e.g. inspection, monitoring, testing, diagnosis, prognosis, etc.) and active maintenance actions (e.g. repair, refurbishment).

IREN Ambiente with her big volume of heavy vehicles relies on the maintenance of the fleet to maintain operative the services that the business unit must do for the different cities where she operates.

In this big context, with the help of the normative UNI EN 13306:2018, different typologies of maintenance are possible:

- preventive maintenance: maintenance carried out intended to assess and/or mitigate degradation and reduce the probability of failure of an item;
- scheduled maintenance: maintenance carried out following a specified time schedule or specified number of units of use;
- predetermined maintenance: preventive maintenance carried out in following intervals of time or number of units of use but without previous condition investigation;
- corrective maintenance: maintenance carried out after fault recognition and intended to restore an item into a state in which it can perform a required function;
- extraordinary maintenance: non-recurring operations with an elevated cost compared with the substitution of the good and the ordinary maintenance that will produce future economic benefits for the business unit for which the economic return can be predetermined.

To better understand the overall picture in figure [1] is reported how the regulation divides the possible maintenance processes that can be carried out:

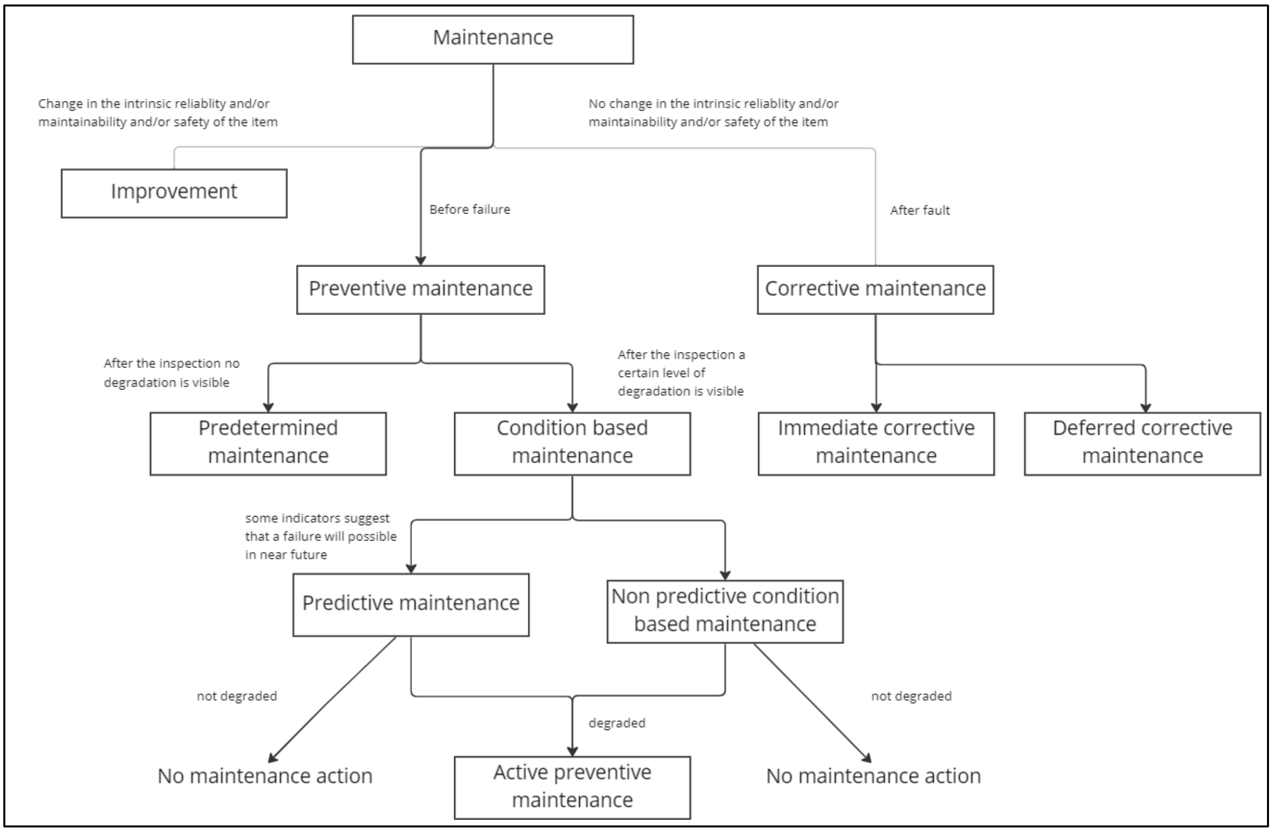

Figure 1. Overall picture depicting the different levels of maintenance

As reported in figure [1] all the maintenance processes with except for the improvement are defined as ordinary maintenance processes.

The normative UNI EN 11063:2017 gives a summary of what is intended as an ordinary maintenance process.

Speaking about vehicle or equipment all the maintenance processes that can be organizational, operative or of design carried out during the life cycle of the good are intended as ordinary maintenance. [2]

This category includes all the operations made to maintain the optimal integrity status and the original or present functional characteristics of a vehicle or an equipment, to counter the normal degradation, to ensure the predetermined life cycle of the good and to restore the availability of it after a failure. [2]

All these interventions don't modify the original characteristics of the good in terms of specifications and the destination of use.

Regarding the improvement the regulation UNI EN 13306:2018 defines it as:

"combination of all technical, administrative and managerial actions, intended to ameliorate the intrinsic reliability and/or maintainability and/or safety of an item, without changing the original function". [1]

In this context a typology of maintenance possible is the extraordinary one.

In IREN Ambiente, the extraordinary maintenance process takes place when the interventions have the target to improve the quality of the vehicle or adapting it to new security standards according to regulations.

These kinds of operations can:

- extend the useful life of the vehicle or equipment;
- improve the maintainability of the vehicle or equipment;
- improve the efficiency of the jobs that the vehicle or the equipment is designed to do.

Every extraordinary maintenance process doesn't modify the original characteristics of the vehicle or equipment in terms of structure, constructive values and nameplate data and doesn't lead to any variations in the destination of use of the vehicle or equipment itself.

In chapter [4.1] the accountability of the maintenance processes has been deeper analyzed.

In the maintenance field is important, to take into account the efficiency of the maintenance processes, and the analysis of different KPIs.

KPIs are powerful instruments useful to better understand if the maintenance processes are developed in a correct way and can be monitored to demonstrate possible improvements related with a new management in the maintenance workflow.

When the performances of the item are not the one expected, the management defines new strategies to improve the actual resources available. In this scenario KPIs are useful indicators able to help the management staff to better understand where to operate.

In this sense is useful to define the targets of what can be achievable with an item or a group of items and so define the main goals.

1.2 Economic KPIs, general definitions and application context in the maintenance engineering

According to regulation UNI EN 15341:2019 the KPIs can be computed and evaluated:

- periodically by defining a time in which the results are compared in terms of what is: budgeted, expected, predicted and planned;
- on a spot basis for specific reports or audits.

The period of time decided for the analysis and monitoring depends on the organization's targets and jobs.

The maintenance function can be seen as an integration of different sub-functions that compose the physical asset management. [3]

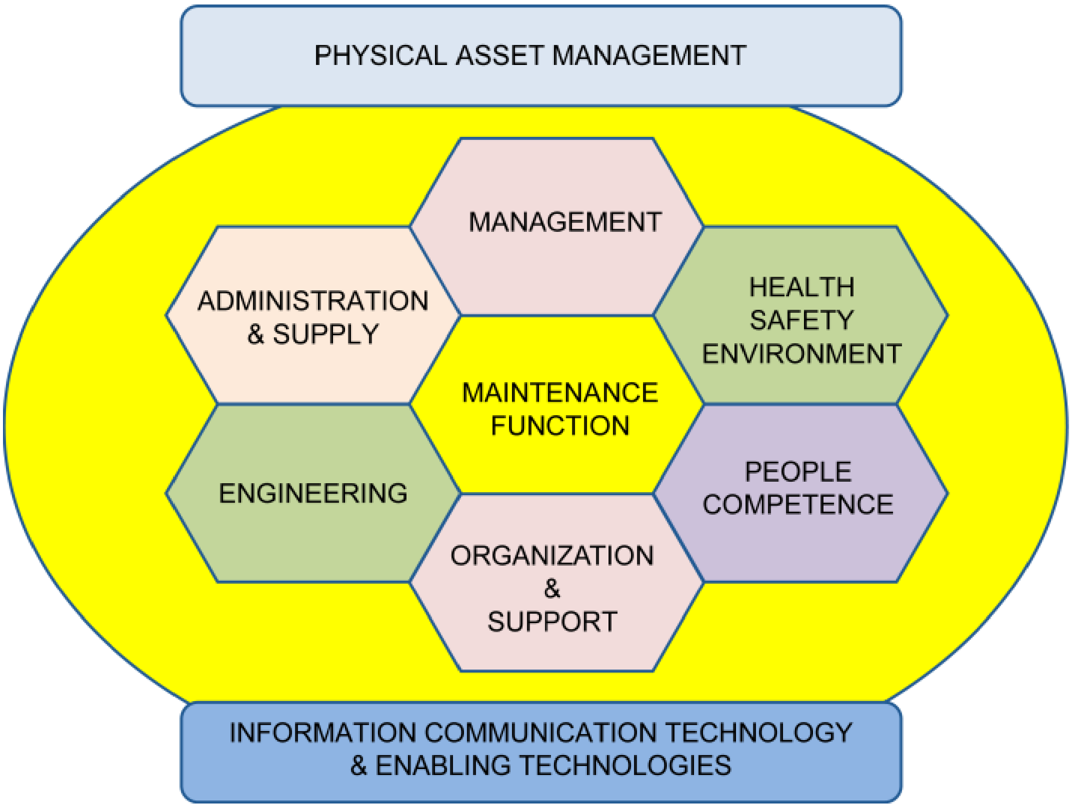

Figure 2. Sub-functions identification

The sub-function "administration and supply" covers different areas like the accounting of the activities and the supply chain management. The KPIs in this sub-category have the target to support the annual economic maintenance plan and budget for the successive year and give an objective photography on how the economic resources are invested in the different kind of maintenance processes. [3]

Regarding these KPIs the most relevant in the administration and supply field are:

$$RMC = \frac{TMC}{PARV} \tag{1}$$

where:

- RMC it's the relative maintenance costs [%];
- TMC it's the total maintenance costs [€];
- PARV it's the physical asset replacement value that is the estimated amount of capital that can be required to build the existing physical asset [3].

$$MCI = \frac{TPMI}{TMC} \tag{2}$$

Where:

- MCI it's the maintenance contribution related to investments [%];
- TPMI it's the cost for the tasks performed by maintenance for investments. In this indicator there are all the costs related to extraordinary maintenance processes including also revamping and retrofitting processes [€].

$$CMO = \frac{TMC + UCM}{QO} \tag{3}$$

Where:

- CMO it's the contribution of maintenance on output;
- UCM it's the unavailability cost due to maintenance related to the down-time of the item [€];
- QO it's the quantity of output as standard or effective.

$$CIP = \frac{IMPC}{TMC} \tag{4}$$

Where:

- CIP it's the contribution of internal personnel cost [€];
- IMPC it's the internal maintenance personnel cost that is the one linked with the operative workers that acts directly on the item to maintain [€].

$$CIPC = \frac{IPC}{TMC} \tag{5}$$

Where:

- CIPC it's the contribution of indirect personnel cost [€];
- IPC it's the total indirect personnel cost related to managers and maintenance engineers involved in the maintenance workflow [€].

$$CSPM = \frac{TCSP + MU}{TMC} \tag{6}$$

Where:

- CSPM it's the contribution of spare parts and material cost [€];
- TCSP it's the total costs of spare parts intended as the costs for the destinated spare parts and coded the coded one that are explained in chapter [4.1];
- MU it's the total costs of the material and consumables used to complete the maintenance order [€].

Regarding the different maintenance processes, different KPIs definitions are possible according with the typology of the maintenance. For the following KPIs, the only factor that changes is the numerator which is related to the cost of the maintenance involved.

$$CTMP = \frac{X}{TMC} \quad (7)$$

Defining CTMP as the total cost of the specific maintenance typology, in formulation (7) the numerator X can assume different meanings like:

- CCM is the cost of the corrective maintenance;
- CPM is the cost of the preventive maintenance.

1.3 Technical KPIs, general definitions and application context in the maintenance engineering

The technical KPIs are referred to as unit of time [hours] and not costs as seen in chapter [1.2]. Also for technical KPIs, they can be analyzed on a spot basis or periodic bases according to European Standard UNI:EN 15341:2022.

$$MTBF = \frac{TOT}{NF} \quad (8)$$

Where:

- MTBF it's the meantime between failures expressed in the unit of time (for example hours);
- TOT it's the total operating time intended as the time in which the item is correctly operating [h];
- NF it's the number of failures.

$$MRT = \frac{TTR}{NF} \tag{9}$$

Where:

- MRT it's the mean time to repair [h];
- TTR it's the total time to repair, it takes into account all the maintenance phases needed to repair the item [h].

$$ROF = \frac{ANF}{AOT} \tag{10}$$

Where:

- ROF it's the rate of failures expressed in N°/year;
- ANF it's the annual number of failures;
- AOT it's the annual operating time.

Referring to different typologies of maintenance processes different KPIs are present. Again, as seen for the previous chapter [1.1], only the numerator changes. In all the following definitions the KPIs have the same denominator which is the total down-time due to maintenance reasons (TDT).

The TDT can be interpreted as the time in which the item is not able to complete his mission.

$$CM = \frac{DTCM}{TDT} \tag{11}$$

Where:

- CM is the KPI referred to the down-time related to corrective maintenance processes [%];
- DTCM is the down-time due to corrective maintenance processes [h].

$$IM = \frac{DTIM}{TDT} \tag{12}$$

Where:

- IM is the KPI referred to the improvement maintenance processes [%];
- DTIM it's the down-time due to improvement maintenance processes [h].

$$CBM = \frac{DTCB}{TDT} \tag{13}$$

Where:

- CBM is the KPI referred to the condition-based maintenance processes [%];
- DTCB is the down-time due to condition-based maintenance processes [h].

$$PM = \frac{DTPM}{TDT} \tag{14}$$

Where:

- PM is the KPI referred to the predetermined maintenance processes [%];
- DTPM is the down-time due to predetermined maintenance processes [h].

$$PMV = \frac{DTPMV}{TDT} \tag{15}$$

Where:

- PMV is the KPI referred to the preventive maintenance processes [%];
- DTPMV is the down-time due to preventive maintenance processes [h].

In chapter [2.1] thanks to the UNI 11440:2022, written by the administrative staff of AMIAT (society part of IREN Ambiente that operates in the city of Turin), the different general KPIs used in the maintenance engineering will be rooted in the operating context of IREN Ambiente.

2. Registry of the fleet, service codes and useful KPIs in the operative context of IREN Ambiente.

The vehicles present in IREN Ambiente (or IAm) have their own data stored on SAP PM, a software examined in chapter [3.2].

IAm controls different societies in different cities:

- AMIAT for Turin with a number of operating vehicles of: 1185;
- IAm itself, operating in Piacenza, Parma and Reggio Emilia with a number of vehicles of: 476;
- ACAM La Spezia, society owner of: 141;
- ASM Vercelli, operating in Piemonte and owner of: 111.

For all the cities where IAm operates, in the context of urban hygiene, and where the societies controlled by her operate a certain number of reserves are calculated as function of the number of work shifts and failure rates.

2.1 Record of the fleet according with the normative UNI 11440 and budget plan.

In IREN Ambiente the registry of the fleet is done following different classifications in according with their services. The UNI 11440:2022 gives a classification for the vehicles and equipment. Every subcategory is then divided again on different basis.

Given the typology of the vehicle or equipment and the subcategory a code is generated in IREN Ambiente and is named "CD_UNI".

The "CD_UNI" is then deeper detailed with another code called "CODICE DI GRUPPO" where two other letters are added to the "CD_UNI". This code is the one that defines uniquely the typology of vehicle or equipment. The same "CD_UNI" can have different "CODICE DI GRUPPO"; so, a vehicle can be of the same typology but can have different characteristics because of different equipment attached.

An example of division for the rear compactors is reported in figure [3], while in figure [4] a scheme reporting how the vehicles and equipment are divided is shown.

Rif_UNI_Tipologia Mezzo	Rif_UNI_Descrizione	CD_UNI	CD_UNI	Rif_UNI_Tipologia Mezzo	CODICE DI GRUPPO	CODICE SAP	DESCRIZIONE SAP
Autocompattatori posteriori	Mini (mtt <= 3,5 t) limite fra patente B e patente C	AAP10	AAP10	Autocompattatori posteriori Mini (mtt <= 3,5 t)	AAP10BA	WV-AAP10BA	COST.POST.MINI
			AAP10		AAP10BP	WV-AAP10BP	COST.POST.MINI.PED
			AAP10		AAP10AE	WV-AAP10AE	COMP.POST.MINI
	Leggero (3,5 t < mtt = 7,5 t)	AAP20	AAP20	Autocompatattori posteriori Leggero (3,5 t < mtt = 7,5 t)	AAP20AE	WV-AAP20AE	COMP.POST.LEG
			AAP20		AAP20AF	WV-AAP20AF	COMP.POST.LEG.VETRO
			AAP20		AAP20BA	WV-AAP20BA	COST.POST.LEG.VAS
			AAP20		AAP20BB	WV-AAP20BB	COST.POST.LEG.BIVAS
	Medio (7,5 t < mtt < 18 t)	AAP30	AAP30	Autocompatattori posteriori Medio (7,5 t < mtt < 18 t)	AAP30AR	WV-AAP30AR	COMP.POST.MED.RIB
			AAP30		AAP30AD	WV-AAP30AD	COMP.POST.MED
			AAP30		AAP30AP	WV-AAP30AP	COMP.POST.MED.PED
	Pesante (18 t <= mtt <= 26 t)	AAP40	AAP40	Autocompatattori posteriori Pesante (18 t <= mtt <= 26 t)	AAP40AD	WV-AAP40AD	COMP.POST.PES
			AAP40		AAP40AP	WV-AAP40AP	COMP.POST.PES.PED
			AAP40		AAP40CA	WV-AAP40CA	VOLTAB.PES
			AAP40		AAP40CP	WV-AAP40CP	VOLTAB.PES.PED
	Ultrapesante (mtt > 26t)	AAP50	AAP40	Autocompatattori posteriori Pesante (18 t <= mtt <= 26 t)	AAP40AR	WV-AAP40AR	COMP.POST.PES.RIB
			AAP50		AAP50CA	WV-AAP50CA	VOLTAB.ULTRAP

Figure 3. Example of subdivision for rear compactors according with UNI 11440

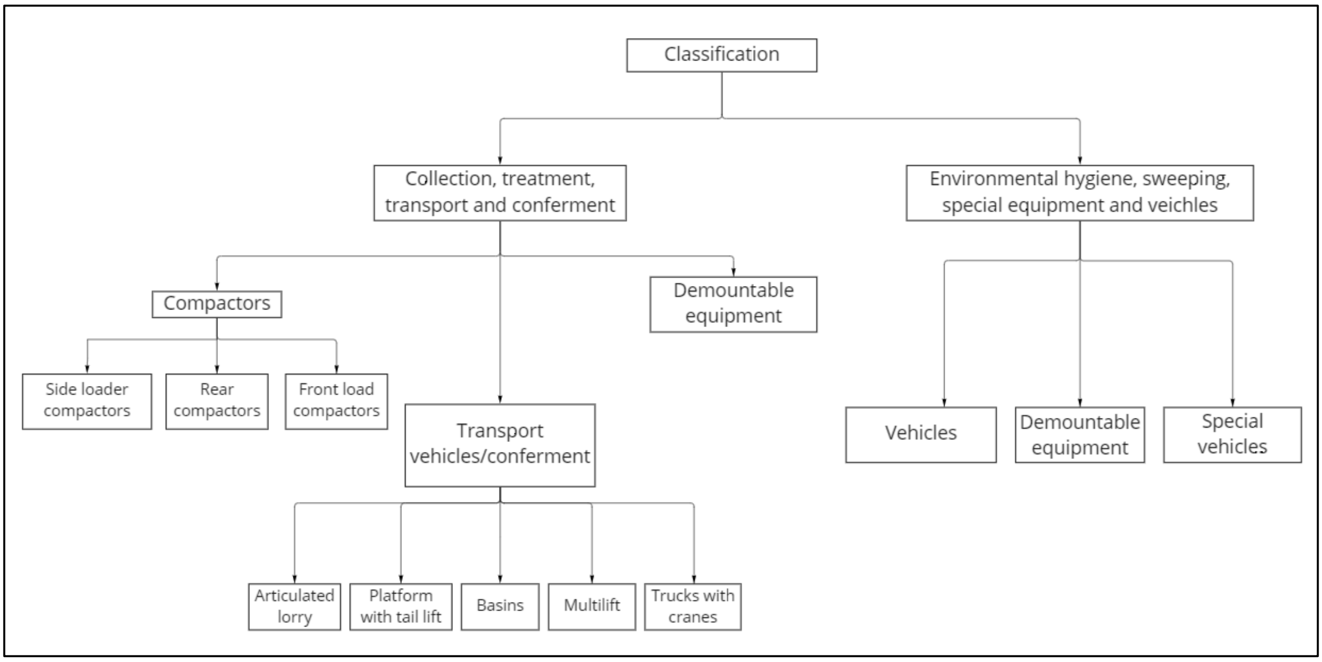

Figure 4. Scheme of how the division of the fleet is done in IREN Ambiente

Compactors, transport vehicles and demountable equipment are then divided again on weight basis.

Vehicles for the environmental hygiene, sweeping, special equipment and vehicles are divided in:

- auxiliary vehicles with gross vehicle weight lower than 3,5 t like motorcycles and quadricycles;
- suction sweepers;
- mechanical sweepers;
- road washers;
- bin washers;
- sewer cleaning equipment;
- leaf vacuums;
- snowploughs;

- salt spreaders.

The demountable equipment in the two categories shown in figure [4] are different. In case of collection, treatment, transport and conferment demountable equipment are caissons, while in the other case are leaf vacuums, snowploughs, salt spreaders and road washers.

As previously mentioned in the chapter [1.1] the KPIs need to be contextualized in the operative reality of IREN Ambiente.

When calculating a KPI the ratio between the numerator and denominator must be referred to the same activity or to the same item (vehicle, equipment or group of them) in the same period.

These performance indicators can be used to evaluate the performances of a group of vehicle or equipment identified by the same "CODICE DI GRUPPO".

Different services are retained as strategic in the business unit and these services are the ones for which the city pays IREN Ambiente to complete the various missions; these services are listed in the budget plan.

The budget plan is based on the zones of the cities in which there are certain services, defined by the projecting department, that must be satisfied. In relation to the services and the zones that needs to be served the closest depot from which the vehicle starts its mission is decided. Every depot has his necessities given by the zones to serve. In relation with to necessities the vehicles are associated and the reserves calculated and every zone is made of different itineraries that the vehicles must cover.

2.2 KPIs in the field of environmental hygiene

In IREN Ambiente the KPIs can be used for the annual/semestral reports with the possibility to check, on a spot basis, how the maintenance processes are running and for the evaluation of the "make or buy" intended as the analysis performed to understand if external maintenances for some operations can be more profitable or not.

KPIs can also support the estimation of the standard costs for the vehicles or equipment referring to the unit of measurements used in the environmental hygiene context, so the hours planned for completing a service, the meters of road swept by the sweeper, the tons of junk delivered to the plants etc.

The results expected from a correct evaluation of the KPIs listed in this chapter are:

- the optimization of the investments/disinvestments plan for the fleet of vehicles and equipment to make them more efficient and as a direct consequence lower down the number of reserves;
- ensure a correct and uniform use of the vehicle fleet;
- give the various workshops the instruments to optimize the maintenance processes, allowing them to take actions primarily on the typology of vehicles retained as strategic by the services.

In chapters [1.2] and [1.3] the general KPIs in the maintenance processes were defined. In this chapter the KPIs for the operative context of IREN Ambiente are described.

Economic KPIs are defined in formulations (16),(17),(18),(19),(20),(21),(22):

$$E1 = \frac{TMC}{AF} \quad (16)$$

$$E2 = \frac{ICP + IMPC}{TMC} \quad (17)$$

$$E3 = \frac{CTT}{TMC} \quad (18)$$

$$E4 = \frac{TCSP}{TMC} \quad (19)$$

$$E5 = \frac{CCM}{TMC} \quad (20)$$

$$E6 = \frac{CPM}{TMC} \quad (21)$$

$$E7 = \frac{CEM}{TMC} \quad (22)$$

Where:

- E1 is the KPI used to understand how the costs are divided on every vehicle belonging to the active fleet;
- E2 is the KPI used to understand how the costs for the personnel are divided on the total maintenance cost;
- E3 is the KPI used to understand how much important the costs for the third parties maintenance processes are, referring to the total maintenance costs;
- E4 is the KPI used to understand how much impactful the spare parts costs, referring to the total maintenance cost;
- E5 is the KPI used to understand how much impactful the corrective maintenance processes are on the total maintenance cost;
- E6 is the KPI used to understand how much impactful the preventive maintenance processes are on the total maintenance cost;
- E7 is the KPI referred to the extraordinary maintenance and is used to weight the extraordinary maintenance processes costs with respect to the total maintenance cost.

And:

- TMC is the total maintenance cost defined in chapter [1.2];
- AF is the active fleet intended as the number of vehicles and equipment including the ones stopped for maintenance processes;

- IPC, IMPC are the personnel costs defined in chapter [1.2];
- CTT is defined as the cost for the acts of intervention done by third parties;
- TCSP is the total cost for the spare parts defined in [1.2];
- CCM is the cost of the corrective maintenance processes;
- CPM is the cost of the preventive maintenance processes;
- CEM is the cost of the extraordinary maintenance processes.

Regarding the technical KPIs, the terms in the various equations will be referred to unit of time and not costs.

$$T1 = \frac{TNAM}{(TTA + TNAM)} = \frac{TNAM}{TT} \tag{23}$$

$$OEE = \frac{TOT}{TTA} = \frac{TOT}{TT - TNAM} \tag{24}$$

$$MTBF = \frac{TOT}{TNF} \tag{25}$$

$$MTTR = \frac{TNAM}{TNF} \tag{26}$$

$$MRT = \frac{TTR}{TNF} \tag{27}$$

$$KTCM = \frac{TTCM}{TTMP} \tag{28}$$

$$KTPM = \frac{TTPM}{TTMP} \tag{29}$$

$$KTEM = \frac{TTEM}{TTMP} \tag{30}$$

Where:

- T1 is the KPI useful to understand how much important is the non-availability time due to maintenance processes;
- OEE is the overall equipment effectiveness;
- MTBF is the mean-time between failure;
- MTTR is the mean-time to restoration;
- MRT is the mean-time to repair;
- KTCM is the KPI used to understand how impactful the total time for corrective maintenance is compared to the total time of the maintenance processes;
- KTPM is the KPI used to understand how impactful the total time for preventive maintenance is compared to the total time of the maintenance processes.

And:

- TNAM is the time for which the item is not available due to maintenance reasons;
- TTA is the total availability time;
- TOT is the total operating time;
- TNF is the total number of failures;
- TTR is the total time to repair;
- TTCM is the total time necessary for corrective maintenance processes,
- TTMP is the total time for every kind of maintenance processes;
- TTPM is the total time necessary for preventive maintenance processes.

All these KPIs, except for the MRT, are deeper analyzed and used in the chapter [6] where a case study is developed for the sweepers present in IREN Ambiente while in chapter [7.2] an analysis on how the remoting of data like km, PTO hours and engine hours can be useful to achieve better results in the KPIs and so lower the OPEX.

3. SAP, how it works and the standard software

The word SAP stands for systems, applications and products in the data processing. This corporation produces software able to support the processes of business from different industries and various sizes.

In IREN SPA, the management software used for all the business unit are branded by SAP.

The software developed by SAP have different features:

- work in real-time processing in which all the actions performed on a certain item are immediately executed and visible on the devices that have the authorization to do it;
- are standard software;
- allows integration between different modules meaning that data available in a particular module can also be read on other modules.

SAP provides standard software. This means that the basic functions without modifications can map many business processes in various industries. [4]

SAP software is made of modules where the selection can be performed, basing on the customer decisions; then the SAP system will be adapted during the implementation.

In IREN Ambiente the most important modules used are SAP MM, for the warehouse, SAP PM, for the maintenance processes, SAP WASTE, for scheduling the services the business unit must do for the cities where IREN Ambiente operates and SAP HR for the human resources.

In IREN SPA, and in all her business units, some transitions codes are adapted to the necessities of the process.

This adaption of the system is enabled by Customizing, which allows to set up the system without programming. [4]

For example, there are customized transitions for the maintenance orders like:

- ZIW29 for the visualization of the warnings;
- ZIW39 for the visualization of maintenance orders;
- ZIW49 for the visualization of the operations present in the maintenance orders.

Regarding SAP system the feature to be a software working in real-time is strategic for IREN Ambiente; indeed, every modification in the status of a vehicle or equipment must be visible in real-time in the different departments of the business unit.

The software uses a three-layer client-server architecture, which has the following layers [4]:

1) client (the workplace computer);
2) server (application layer);
3) database (database layer).

In IAm every worker of the administration department has his own laptop given by the business unit. Any modification, directly or indirectly made on the vehicle or equipment, is done through a device that has the permission to do it.

If a request is performed from these devices this one is transferred from the device to the server. Here the database server processes the data of the request and finally transfer them to the database to let them be readable from all the other devices.

Using the client-server architecture allows to operate even if one or more devices are not working, have better security to protect data if the network infrastructure is stable and secure and perform central backup on a periodic or spot basis.

3.1 SAP PM, transitions and how is structured in IREN Ambiente

SAP PM (plaint maintenance) is the module of SAP destinated to the maintenance processes. In IREN SPA all the business units use this module as support for the maintenance workflow.

In SAP PM also the records of the fleet are kept. All the vehicles are registered, and all the useful information used to define the vehicle uniquely, are reported and can be seen using the transitions IE03 or IE36.

For every vehicle are reported the number of equipment (automatically generated in the moment of the creation of an item as an internal key), a description of it, the status and the registration data as shown in figure [5] for the equipment 600691:

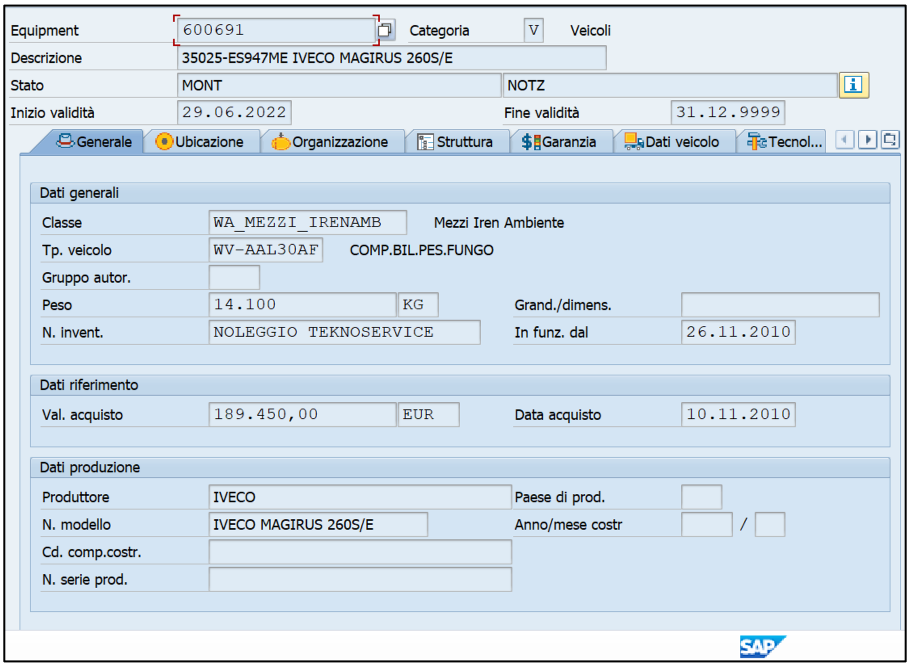

Figure 5. Example of registry for an equipment

The description of the vehicle is composed by:

- the company number that identifies uniquely the item;
- the plate (in case of vehicle);
- the name of the model assigned to the vehicle or the equipment.

Regarding the status, as default, the system automatically assigns DISP. The status DISP stands for an item that has been created but not already assigned to a technical headquarters.

The technical headquarters is defined as the main department that has in charge the maintenance of the vehicle or equipment.

Other possible values that the field “status” can assume are:

- MONT if a vehicle is in service and has been assigned to a technical headquarter;
- DISP OGIN if an item is inactive and is also not able to be maintained;
- FCAN if the item has been cancelled;
- EQSU if the item is an equipment and has been mounted on a vehicle.

Useful information are also reported and divided in different tabs called: general, location, organization, structure, warranty, vehicle data and vehicle technology.

In these tabs the most important data useful also for the maintenance are:

1) typology of the vehicle identified by “CODICE DI GRUPPO” explained in the chapter [2.1];
2) weight of the vehicle;
3) cost of the vehicle or the equipment when it was bought;
4) producer and the model of the vehicle;
5) division of the vehicle;
6) working center defining the location in which the vehicle or equipment is working;
7) ubication defined as the place where the vehicle or equipment is located;
8) center cost and the WBS for the accounting;
9) workshop responsible for the maintenance;
10) structure in which are shown all the equipment attached to the vehicle;
11) data when the warranty starts and ends.

As outlined in chapter [2] IREN Ambiente controls different societies: herself, AMIAT, ASM Vercelli, and ACAM La Spezia. All these societies are identified on SAP as divisions; a vehicle is allocated in a technical headquarter and this one is part of the division. For example, the division assigned to AMIAT on SAP is 3500 while for IAm ASM Vercelli and ACAM are respectively 3000, 1905 and 3600.

In SAP PM two kind of fields can be defined: Standard fields and Characteristic fields.

Standard fields are intended as predisposed cells generated by SAP PM in which information can be written or selected following the typology of field. Characteristic fields are created by the business unit on SAP PM thanks to her IT structure that generates new cells if required by the administration.

The characteristic fields are generated when the already present standard fields are not able to represent a specific condition.

To coordinate the maintenance processes the most important transitions are reported:

- IW21 used to create warnings;
- IW22 used to modify an existing warning;
- IW23 used to visualize an existing warning;
- IW31 used to create a maintenance order;
- IW32 used to modify an existing maintenance order;
- IW33 used to visualize an existing maintenance order;
- IW28 used to modify a report of warnings;
- IW29 used to visualize a report of warning;
- IW38 used to modify a report of orders;
- IW39 used to visualize a report of orders.

The warnings generated from these transitions can be blocking or not. If they are “blocking warnings” the vehicle is stopped from work without any possibilities to complete his mission. If not, it will be repaired as soon as possible but the actual failure doesn’t affect the possibility to complete the mission.

In this chapter, the focus will be on how these transitions are implemented and can be useful for the case study analyzed in chapter [6].

To create a correct report where the KPIs can be evaluated on a periodical basis is important to understand how these transitions works.

Looking at the PDCA cycle reported in figure [6], all the transitions listed before are useful to calculate the different KPIs that are considered in the “plan” phase where the targets are defined, in the “do” and “check” phase where they are measured and in the “act” phase where the actuals results are compared with the one planned before and where practical actions are taken.

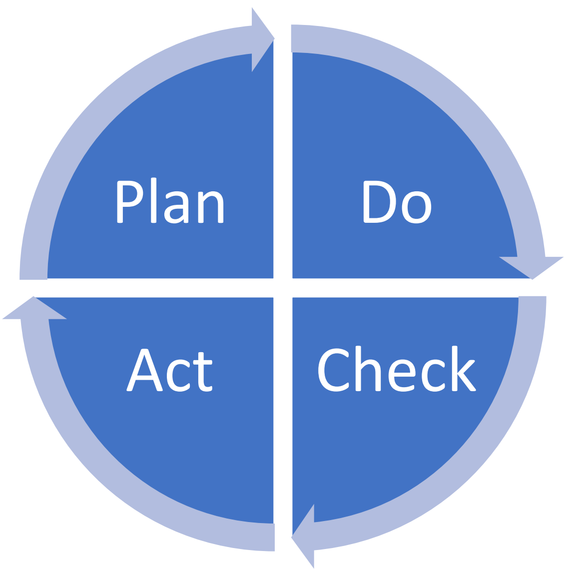

Figure 6. PDCA cycle

When creating reports, the transitions IW29 for warnings and IW39 for maintenance orders are the most powerful and used. These two allow, selecting a "CODICE DI GRUPPO" or "CD_TIP", to have report about warning and maintenance orders.

Regarding the IW29 different status can be selected according with the warning searched:

- an "open warning" that means a warning which is not solved and needs to be evaluated by the workshop manager who decides to create a maintenance order or not;
- a "postpone warning" that means a warning automatically generated by the system because of a programmed maintenance program that is postponed by the workshop manager;
- an "in elaboration warning" that means a warning that has been evaluated by the workshop manager who decided to create a maintenance order that is not already completed;
- a "closed warning" that is a warning that has been closed with the maintenance order associated.

In figure [7] is reported a display of the transition IW29 before the actual research where the filters can be imposed.

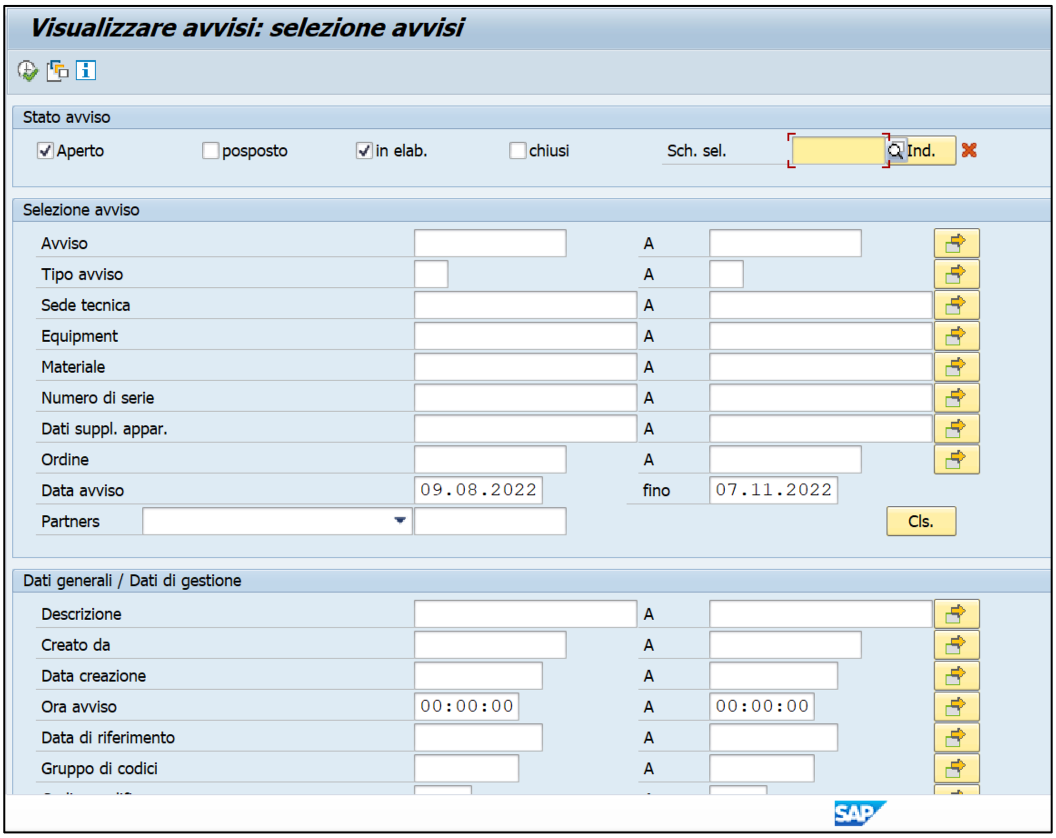

Figure 7. IW29 transition

As we said previously to correctly calculate a KPI is mandatory to evaluate the same vehicle or equipment or the same "CODICE DI GRUPPO" that stands for the same group of vehicles or equipment which are of the same typology.

The most common way to search inside these commands is to use an excel database (extrapolated from SAP PM), filter the vehicles or equipment basing on the “CODICE DI GRUPPO” or “CD_TIP” and then taking the number of equipment associated. After this, we will come up with multiple selections of number of equipment that will be searched in the transitions.

In the following steps, an example is performed.

In IREN Ambiente one of the most important typologies of vehicles is the TNNE (as CD_TIP) or the AAL30AF (as CODICE DI GRUPPO). This kind of vehicle is a side loader compactor that operates on both sides.

As explained before, an excel database in which all the vehicles are present is used. This excel database is extrapolated thanks to SAP. Part of the excel database in reported in figure [8]:

Società	Categoria	N Aziendale	Descrizione telaio	Codice di Gruppo	DESCRIZIONE SAP	Codice Tipologia
1905	V	V-A1	V-A1 EG074TJ IVECO MAGIRUS A410T/E4	AAP50CP	VOLTAB.ULTRAP.PED	FDAC
1905	V	V-A10	V-A10 GF059HV VOLVO 320	AAP40AD	COMP.POST.PES	FDAA
1905	V	V-A11	V-A11 GF060HV VOLVO 320	AAP40AD	COMP.POST.PES	FDAA
1905	V	V-A12	V-A12 EA172VJ IVECO EUROCARGO 180/E4	AAP30AD	COMP.POST.MED	FDAD
1905	V	V-A13	V-A13 EA171VJ IVECO MAGIRUS A260/E4.	AAP40AD	COMP.POST.PES	FDAA
1905	V	V-A14	V-A14 ET771GJ IVECO STRALIS AD260S3Y/P.c	AAP40AP	COMP.POST.PES.PED	FDAA
1905	V	V-A2	V-A2 FA039NJ IVECO EUROCARGO 150E25K	AAP30AD	COMP.POST.MED	FDAD
1905	V	V-A3	V-A3 DV937MN IVECO MAGIRUS 260/S / E4	AAP40AP	COMP.POST.PES.PED	FDAA
1905	V	V-A4	V-A4 FD044FZ IVECO MAGIRUS 340	AAP50CA	VOLTAB.ULTRAP	FDAC
1905	V	V-A5	V-A5 FR017YP IVECO MAGIRUS AD260SY/PS	AAP40AP	COMP.POST.PES.PED	FDAA
1905	V	V-A6	V-A6 FW000RK IVECO IG190EL2CA	AAP30AP	COMP.POST.MED.PED	FDAD
1905	V	V-A7	V-A7 FW091RK IVECO IG190EL2CA	AAP30AD	COMP.POST.MED	FDAD
1905	V	V-A8	V-A8 FW092RK IVECO 2Y3C IC09	AAP40AD	COMP.POST.PES	FDAA
1905	V	V-A9	V-A9 GC042XC VOLVO 330	AAP40AD	COMP.POST.PES	FDAA
1905	V	V-C1	V-C1 FR049YP IVECO AD260SY/PS	ABM40EA	LIFT.PES	TAMM

Figure 8. TNNE example

To search the warnings for this typology of vehicle, thanks to the support of the excel sheet where all the active vehicles are present, is possible to impose a filter for the TNNE like in figure [9].

Società	Categoria	N Aziendale	Descrizione telaio	Codice di Gruppo	DESCRIZIONE SAP	Codice Tipologia
3500	V	35001	35001-BY677KZ IVECO MAGIRUS 260E31	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35015	35015-ED212ZK IVECO MAGIRUS 260S/E	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35024	35024-EX478DH IVECO MAGIRUS 260S/E	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35025	35025-ES947ME IVECO MAGIRUS 260S/E	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35033	35033-ET646DL IVECO MAGIRUS AG	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35034	35034-FN654FH IVECO MAGIRUS AD260S	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35035	35035-FN653FH IVECO MAGIRUS AD260S	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35036	35036-FY293HV IVECO MAGIRUS AD260S	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35037	35037-GB973ZY IVECO MAGIRUS AD260SY/PS	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35038	35038-GB974ZY IVECO MAGIRUS AD260SY/PS	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35046	35046-GE828MF IVECO MAGIRUS AD260SY/PS	AAL30AF	COMP.BIL.PES.F90	TNNE
3500	V	35047	35047-GE829MF IVECO MAGIRUS AD260SY/PS	AAL30AF	COMP.BIL.PES.F90	TNNE

Figure 9. TNNE filtered for society

As seen in chapter [3.1] the societies in IREN Ambiente are defined with a code number; the number 3000 is the one linked with IREN Ambiente herself, the number 3500 is the one assigned to AMIAT, 1905 the one assigned to ASM Vercelli and 3600 the one assigned to ACAM La Spezia.

In the following example in figure [10] the research has been done for the warnings with a closed status from 01/09/2022 until the 10/10/2022 for AMIAT.

Visualizzare avvisi: lista avvisi

Tp.	Equipment	Avviso	Ordine	Inizio guasto	Fine guasto	FermoMacch	Descrizione	Sede tecnica	Div.	CLavResp
ZP	600395	5000060393	6000055354	04.07.2022	04.07.2022		SEDUTA DI REVISIONE ANNUALE MEZZI PESANT	A-PM-TO-GERM	3500	TOE-O
ZR	602203	5000060396	6000055386	04.07.2022	05.07.2022		Olio Idraulico	A-PM-TO-GERB	3500	TOE-G
ZR	602267	5000060493	6000055458	05.07.2022	05.07.2022		Jib 2 non a roposo	A-PM-TO-GERB	3500	TOE-I
ZR	602541	5000060462	6000055436	05.07.2022	05.07.2022		rabbocco vaschetta grasso	A-PM-TO-GERM	3500	TOG-O
ZR	602543	5000060573	6000055572	06.07.2022	07.07.2022		Filtro Gasolio	A-PM-TO-GERM	3500	TOG-O
ZR	602544	5000060580	6000055607	06.07.2022	07.07.2022		Varie	A-PM-TO-GERM	3500	TOG-O
ZR	602203	5000060721	6000055690	07.07.2022	08.07.2022		non rlieva il peso	A-PM-TO-GERB	3500	TOE-I
ZR	602543	5000060834	6000055785	08.07.2022	09.07.2022	X	Barra non funzionante	A-PM-TO-GERM	3500	TOG-O
ZR	602544	5000060735	6000055741	08.07.2022	08.07.2022		JIB	A-PM-TO-GERM	3500	TOG-O
ZR	602542	5000060889	6000055886	11.07.2022	12.07.2022		spia freni accesa	A-PM-TO-GERM	3500	TOG-G
ZR	602203	5000061068	6000056038	12.07.2022	13.07.2022		guarnizione cassone guasta	A-PM-TO-GERB	3500	TOE-O
ZR	601234	5000061448	6000056385	16.07.2022	16.07.2022		ALLARME ATTREZZ. FUORI SAGOMA	A-PM-TO-GERB	3500	TOE-O
ZR	602203	5000061421	6000056362	16.07.2022	18.07.2022		Imbocco raccordo benna scoppiato	A-PM-TO-GERB	3500	TOE-O
ZR	601538	5000061526	6000056491	18.07.2022	18.07.2022		Grossa perdita olio idraulico	A-PM-TO-GERB	3500	TOE-O
ZR	602203	5000061590	6000056522	19.07.2022	20.07.2022		Rabbocco olio idraulico	A-PM-TO-GERB	3500	TOE-O
ZR	602544	5000061897	6000056833	22.07.2022	26.07.2022		fermo della valva polipo mancante	A-PM-TO-GERM	3500	TOG-O
ZR	602267	5000062011	6000056846	25.07.2022	27.07.2022		spia prefiltro	A-PM-TO-GERB	3500	TOE-O
ZR	601538	5000062223	6000057124	27.07.2022	02.08.2022	X	rabbocco olio motore + astina livello	A-PM-TO-GERB	3500	TOE-O
ZR	601538	5000062211	6000057126	27.07.2022	03.08.2022		girella + luci + olio idraulico + grasso	A-PM-TO-GERB	3500	TOE-O
ZR	602267	5000062237	6000057127	27.07.2022	27.07.2022		spia anomalia motore	A-PM-TO-GERB	3500	TOE-O
ZR	601538	5000062631	6000057473	01.08.2022	08.08.2022		faro destro posteriore non funzionante	A-PM-TO-GERB	3500	TOE-O
ZR	602542	5000062677	6000057542	02.08.2022	03.08.2022		perde olio dal cilindro dell'attrezzatur	A-PM-TO-GERM	3500	TOG-O
ZR	602542	5000063191	6000058010	08.08.2022	08.08.2022	X	ruota asse sterz post dx da gonfiare	A-PM-TO-GERM	3500	TOG-O

Figure 10. IW29 example for TNNE in AMIAT

Here are defined:

- kind of warning that is deeper analyzed in chapter [4.2];
- number of equipment associated with the item;
- number of warning and maintenance order associated;
- date reporting when the maintenance order was open;
- date reporting when the maintenance order was closed;
- the “X” flag where the warning is blocking the vehicle and so the vehicle is absolutely stopped to complete any mission assigned;
- a first description of the warning provided by the driver;
- technical headquarter which has the item involved in the warning;
- the division;
- workshop responsible for the maintenance order.

3.2 SAP Waste and the scheduling user interface

SAP Waste is the software in IREN Ambiente where everything regarding the services that the business unit must do for the cities are recorded; here all the itineraries and the missions of the various typologies of vehicles are contained.

The various coordinators present in the different working centers use a dedicated interface to schedule the services, as reported in figure [11], displayed thanks to the command: “ZWA_PIANIFICAZIONE”.

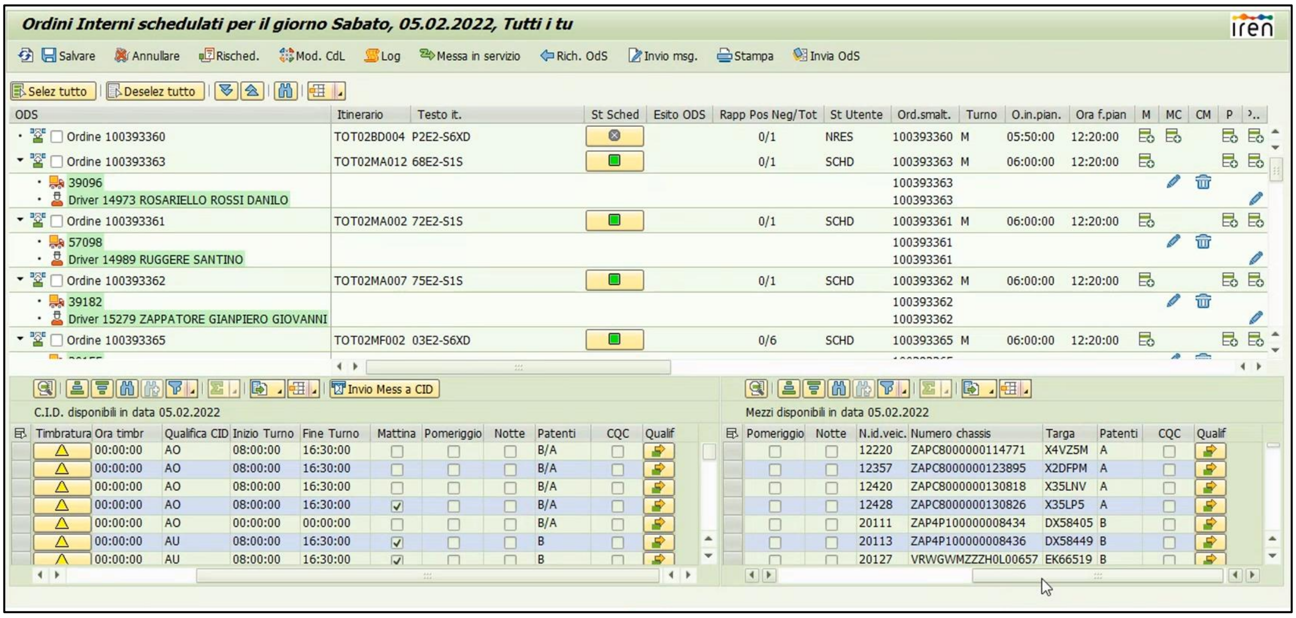

Figure 11. ZWA_PIANIFICAZIONE transition

When launching this transition an automatic schedule is done.

For every disposal order is assigned a vehicle and a driver following a preference order. In case of vehicles the system will search if in the record of the itineraries there is one that usually does this kind of mission.

If this vehicle is green like in the figure [12], it means that it is not stopped from work and so there is no maintenance order associated with a "blocking warning" and the vehicle can be assigned to the order.

Mezzo	Cod Sportello	St.sist.	Tipo Veic	C. lav.	Mattina	Por
	20286	DISP	QDRCCL.N.U.ELET	TOI109Z		
	20289	DISP	QDRCCL.N.U.ELET	TOI109Z		
	20290	DISP	QDRCCL.N.U.ELET	TOI108Z		
	20352	DISP	QDRCCL.N.U.ELET	TOI108Z		
	20357	DISP	QDRCCL.N.U.ELET	TOI108Z		
	20361	DISP	QDRCCL.N.U.ELET	TOI109Z		
	20366	DISP	QDRCCL.N.U.ELET	TOI109Z		
	20372	DISP	QDRCCL.N.U.ELET	TOI109Z		

Figure 12. ZWA_PIANIFICAZIONE vehicles screening

If the vehicle is red, the system will search for a vehicle similar to the one stopped from work. If no other vehicle is available for the same typology the coordinator will assign one that is suitable for the mission according to his work experience.

Associated with the vehicle and the qualifications needed to drive, the operator is assigned.

If the driver is available, he can be assigned, if not the coordinator will search for an alternative one looking at the qualifications of the other drivers.

When the scheduling has automatically performed the status of the order is "SCHD", when no resources are assigned to a specific order, because the system is not able to find the correct vehicle and the preferred driver, the status is "NRES" like shown in figure [13].

Figure 13. Status in transition ZWA_PIANIFICAZIONE

Another possible status can be "SCPZ" that means "partially scheduled", in this case the system can find the correct vehicle but not the driver, or vice versa.

In these two last cases the coordinator needs to act manually on the software to assign the resources. The system doesn't allow to assign two vehicles to the same order but allows to assign two operators to the same vehicle.

Different function buttons like the ones reported in figure [14], are used to add an operator that will help the driver during the mission. The system, thanks to these functions, does a first screening suggesting the operators with the correct qualifications to be assigned to the mission.

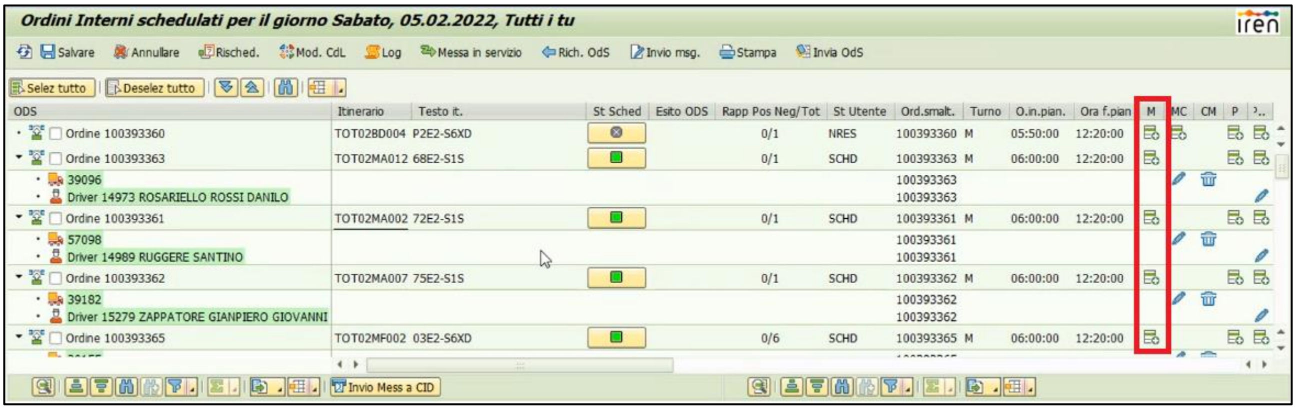

Figure 14. Function buttons in ZWA_PIANFICIAZIONE transition

If the coordinator assigns a person not able to perform the mission with a certain vehicle an error is displayed without any possibilities to proceed on the scheduling.

4. Actual management of how the maintenance order, warnings and warehouse withdrawal are handled in IREN Ambiente with SAP PM

Regarding SAP PM, the software has been adapted to the different needs of IREN Ambiente. Since in this business unit the main goal is not doing maintenance on plants, the maintenance processes have been reviewed and new characteristic fields have been created.

SAP PM, in IREN Ambiente, is the core software linked with the maintenance of the fleet and two different entities are defined to manage the maintenance processes: the warning and the maintenance order.

Regarding the warning:

- the management of it is done on SAP PM;
- the warning is created after a report and can be generated with SAP, SAC or the intranet;
- it contains the information about which vehicle is involved (so the number of equipment);
- every warning is linked with a maintenance order if the maintenance order associated exists.

Regarding the maintenance order:

- it contains all the data necessary to the execution and the final summary;
- it contains the accounting data like the center cost referred to the vehicle or the WBS;
- in every operation listed inside the maintenance order the materials used are reported.

To better understand the maintenance workflow is important, in this first phase, to analyze the organization chart.

All the vehicles of the fleet are driven only by people who work for the business unit and have the eligibility to do it. If a problem is encountered during the use of the vehicle, independently if it is linked with the chassis or the equipment, the coordinator that operates in the WASTE area, with an appropriate interface, will create, using the intranet, a warning specifying the following fields:

- the kind of warning;
- an extensive description of the warning;
- the title related with the warning;
- the equipment;
- the number of km or/and PTO (optional);
- the code linked with the cause (optional).

The kind of warning field can be of three types:

- ZP: Warning used to identify a preventive maintenance operation;
- ZR: Warning used to identify a corrective maintenance operation;
- ZS: Warning used to identify an extraordinary maintenance operation.

After the generation of the warning the workshop manager will create a maintenance order specifying if the vehicle must be stopped from work or not and if the maintenance order can be completed internally or must be performed outside in an appropriate workshop.

If the maintenance order is done internally the correct workers are selected by the workshop manager. If the maintenance order must be done outside, the business unit's validators will contact the proper workshop looking at the contract stipulated; then the vehicle will be sent outside IREN Ambiente.

As there are different kind of warnings there are also different kind of maintenance orders like:

- ZJI2 that identifies a cyclic preventive maintenance order;
- ZJI1 that identifies a corrective maintenance order;
- ZJI3 that identifies an extraordinary maintenance order.

Between the warning and the maintenance order there is a 1 to 1 link, a ZP warning will generate a ZJI2, a ZR warning will generate a ZJI1 and a ZS warning will generate a ZJI3.

It is possible that a warning doesn't create a maintenance order. The reason is related to the fact that, in the phase where the workshop manager decides if the maintenance operations can be done internally or externally, he also understands if the problem is solvable in few minutes or not and if the warning was reporting a real problem or not.

If a maintenance order is done internally the proper spare parts, that need to be used for the various operations, are selected and the maintainer must prepare a list of the materials with the quantities requested. At this point the worker, using the intranet, will check if the spare parts are coded or not; if they are coded he will create an RdM (magazine request).

The RdM can be created:

- directly from the maintenance order, associating for each operation the spare parts needed. Following this procedure, the system will account the costs on the maintenance order with the proper center cost;
- using an intranet interface reported in figure [15].

Figure 15. RDM interface

Following the second option the maintainer will search for the material, selecting the quantities and visualizing the total value of the spare parts.

A date for the withdrawal is assigned and at the checkout, shown in figure [16], the maintainer can fill the WBS/CDC/OI/ODM field with the WBS in case of spare parts needed for extraordinary maintenance processes, the CDC or OI in case the only known data is the center cost of the vehicle or the ODM (maintenance order).

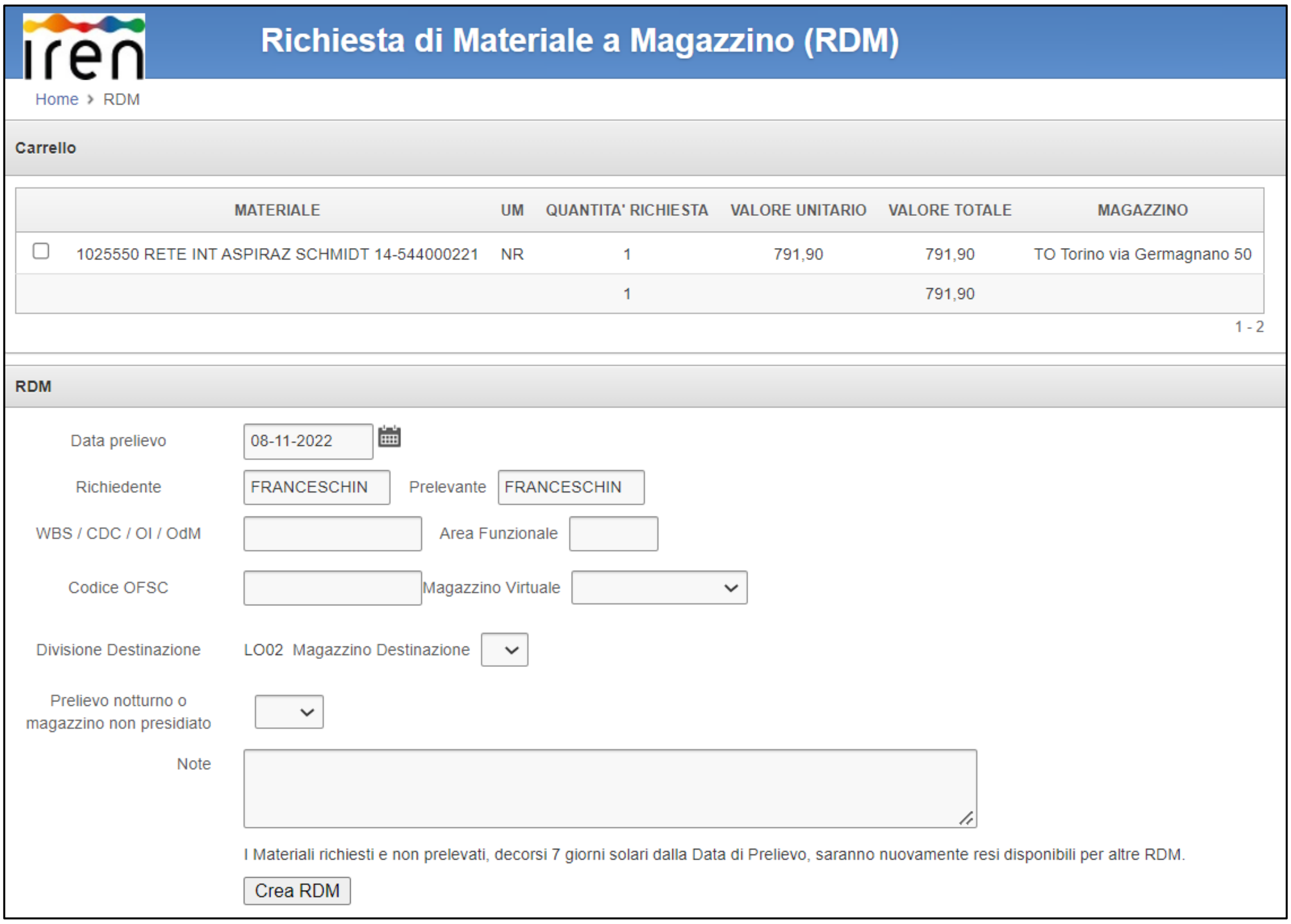

Figure 16. RDM interface

If the spare parts are not present in the interface, the list of the materials is sent to the workshop manager that will validate the request and create a withdrawal voucher. After this step the withdrawal voucher is given to the administration structure that, based on who is the supplier, will search the materials not coded in the contract of the destinated spare parts.

The differences between the coded and the destinated spare parts are reported:

- coded spare parts are managed in a tax warehouse while the destinated spare parts are not managed inside it and after the receipt of the goods are used for completing the maintenance order;
- coded spare parts have usually a minimum amount under which the buying cannot be completed.

The administration of the fleet usually understands if a spare part must be coded or not basing on the amount of order made during a certain period. If a spare part is requested various time for a typology of vehicle that is strategic or for which there is a job expected for the city the good will be coded and then managed in the tax warehouse.

When a vehicle or an equipment needs to be repaired and for the restoration a spare part that is not present in the warehouse is needed the logistic and internal administrative delays have a huge impact on the total amount of time to solve the failure.

In this sense is useful to divide the maintenance operating time in different parts according with the different typologies of operations.

The preventive maintenance process has an operation time that can be divided in:

- the time used to wash the vehicle/equipment;
- the degradations assessment time where the maintainer, after a first visual control, will do a checkup and a deeper inspection of the vehicle or equipment to understand if operations are necessary;
- the logistic and internal administrative delays related to the possibility that, if spare parts are needed, they need to be ordered if not present in the warehouse. This implies that after the creation of the order with the spare part needed there is a time in which the maintainer is not operating on the vehicle/equipment or is doing another operation different from the one where the replacement is involved;
- the active preventive maintenance time where the maintainer does the operations needed on the vehicle or equipment. In some cases, it can be carried out while the item is operating.
- the technical time necessary to perform auxiliary technical actions associated with, but not part of, the maintenance action; [3]
- the time used to verify if the item is correctly operating.

Regarding the time to proceed with corrective maintenance processes, if the maintenance order is done internally, the different parts of the time schedule can be divided in:

- time used to wash the vehicle/equipment;
- the fault diagnosis time needed to understand where the problem is and the entity of it;
- logistic and internal administrative delays;
- the active corrective maintenance time needed to repair the vehicle or the equipment to a status in which it can operates in his destination of use;
- technical time necessary to perform auxiliary technical actions;
- testing time used to verify if the item is correctly operating.

Two schemes about how the operation times for the preventive maintenance processes and the corrective maintenance processes are reported respectively in figure [17] and [18].

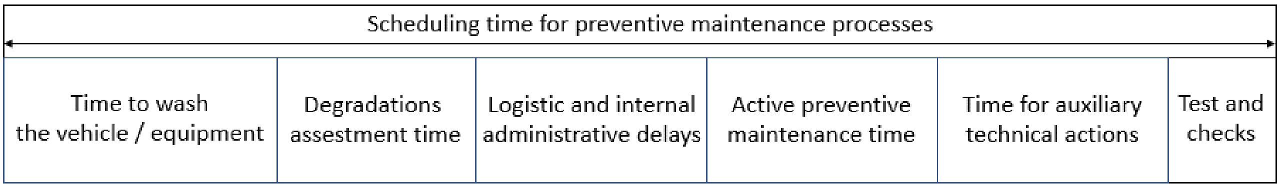

Figure 17. Scheduling time for preventive maintenance processes

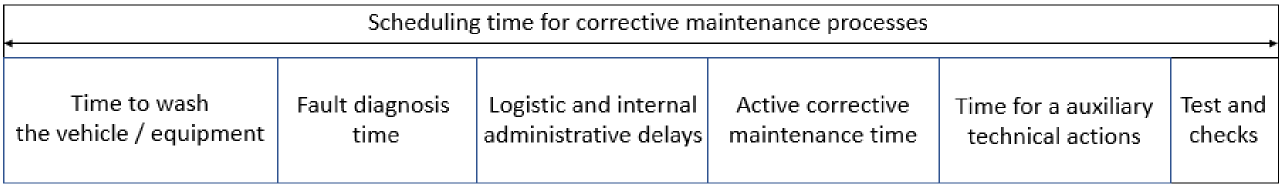

Figure 18. Scheduling time for corrective maintenance processes

4.1 Maintenance costs distribution and business unit policy

To understand how the costs for a maintenance process are broken down a deeper analysis is developed.

All the costs related with an investment are defined as CAPEX while all the costs related to the preservation of a piece of equipment or a vehicle are defined as OPEX.

The accounting of these costs can be done in three different ways on SAP, using:

- WBS (work breakdown structure);
- center cost;
- maintenance order.

When an investment is done, so a vehicle or an equipment is bought, the costs are reversed in the WBS that is created from the budget. WBS are intended as “containers” directly linked with the budget where the costs annual investments of every societies part of IAm are conveyed.

Every investment is linked with a depreciation time that for vehicles is usually 8-10 years.

Another possible investment is the extraordinary maintenance process where the cost related is reversed again in the WBS that can be created for the specific case or can be the one used for the purchase of the vehicle or equipment. Again, in this case, a depreciation time is expected; indeed the policy of IREN Ambiente establishes that for AMIAT the depreciation time is of 10 years in case of vehicles and 8 years for IAm itself.

About OPEX, different possibilities are present:

- corrective maintenance processes;
- preventive maintenance processes.

All the costs related with these kind of maintenance processes converge in a cost center and in the business unit every typology of vehicle has his cost center that centralizes the costs.

If the maintenance order is used for the accounting, all the costs related with to personnel, spare parts and third parties are stored within the maintenance order that is linked with the center cost of the vehicle.

5. Programmed maintenance processes created on SAP PM

The vehicles used in IREN Ambiente can be of two macro-categories.

The first is the one in which some vehicles were designed to do their job without any equipment attached while the second is the one in which the global equipment is composed by a chassis and one or more equipment attached used to complete the missions assigned.

For both these macro-categories maintenance processes, for the preventive part, can be scheduled basing on time or kms traveled.

As seen in chapter [4], the cyclic maintenance is implemented in SAP PM and codified as ZJI2. This kind of maintenance can be seen as a programmed maintenance process.

In IREN Ambiente vehicles and equipment have four measuring points that in SAP system describe the physical and/or logical locations at which a condition is described. In PM, measuring points are located on technical objects so on pieces of equipment or functional locations. [5]

In figure [19] is reported a detail of a sweeper, with the four measuring points defined as:

- PM_CONTACHILOMETRI where the number of km is stored;
- PM_LITRIEROGATI where the number of liters of fuel is stored;
- PM_ORE_PTO where the number of the total hours of power takeoff is stored;
- PM_CONTATORE_ORE where the number of the total hours of the engine is stored.

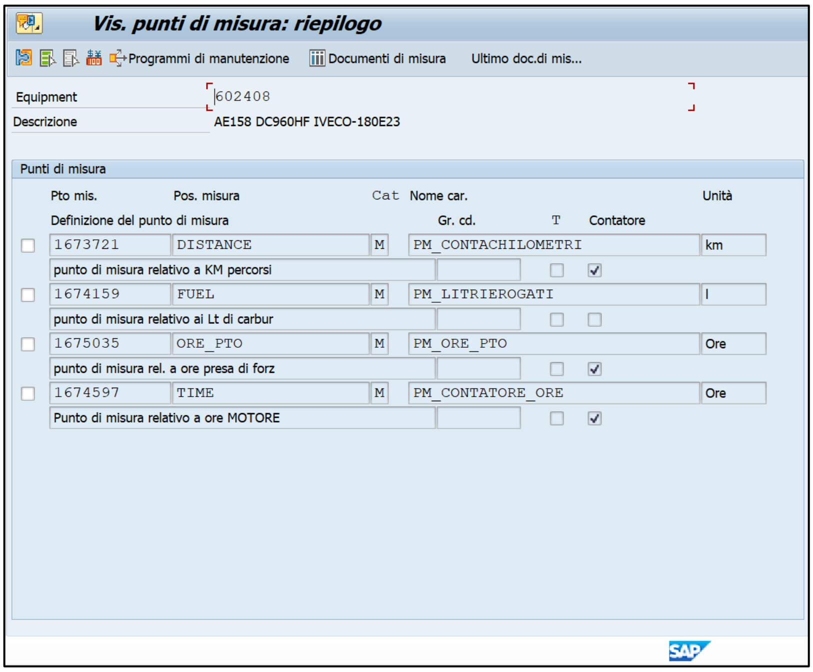

Figure 19. Measuring points on SAP PM

Usually, the two most important measuring points are PM_CONTACHILOMETRI and PM_ORE_PTO for which is associated a programmed maintenance program. The program starts if one of the two measuring points reach the threshold value for which the programmed maintenance is studied.

Selecting one of the four measuring points is possible to see the all the details related with the ZJI2 program. In this case, the PM_CONTACHILOMETRI is selected and the details are reported in figure [20].

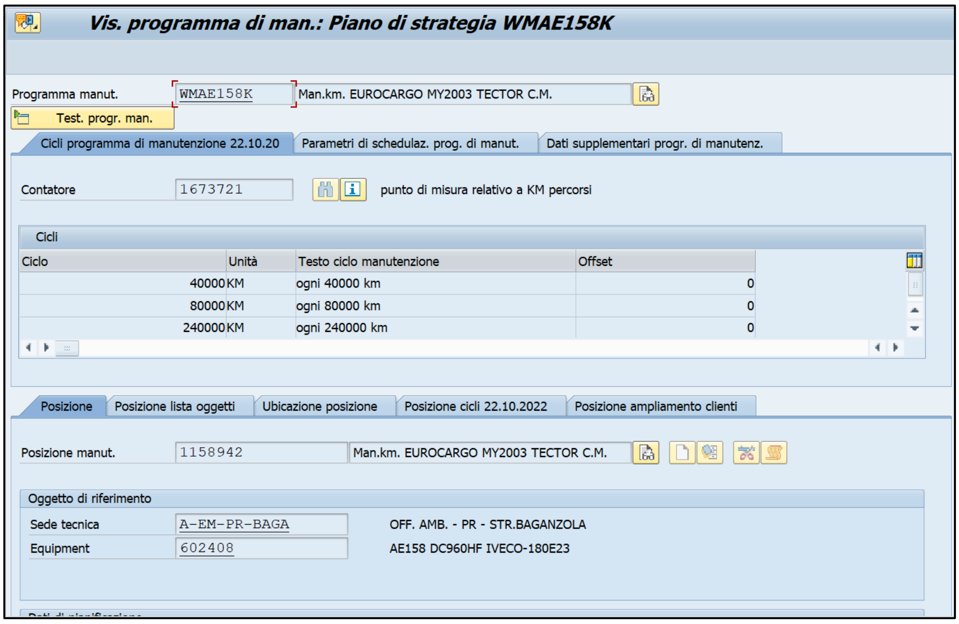

Figure 20. ZJI2 cycle on km's measuring points

As shown in figure [20] the cycle is activated every 40000km, 80000km and 240000km. In every cycle are then reported the operations that the maintainer has to do to complete the maintenance order.

The maintenance programs on SAP PM are defined with some scheduling parameters that are reported in figure [21].

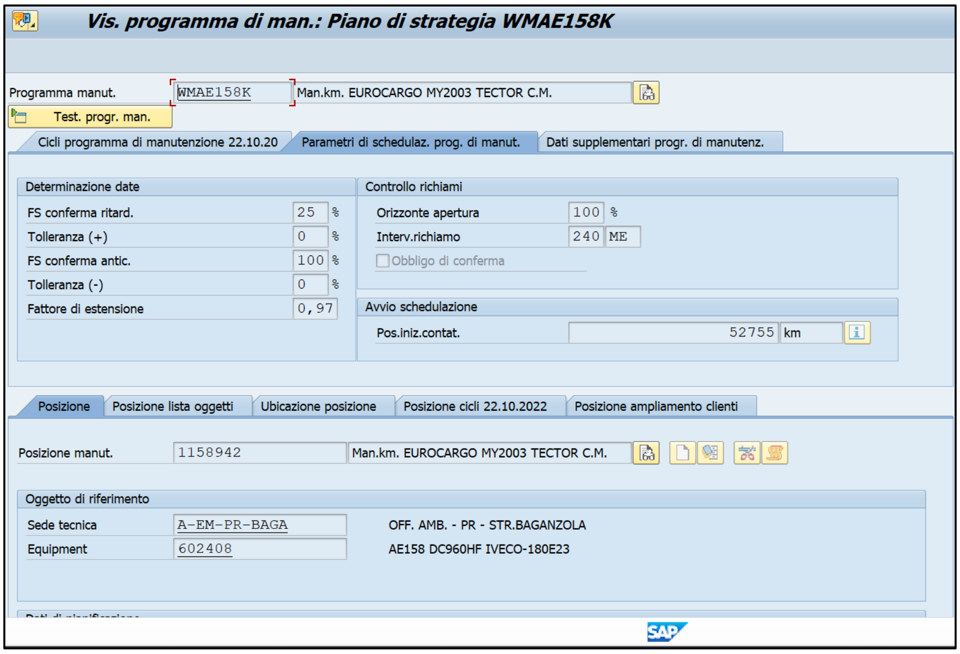

Figure 21. Scheduling parameters for cyclic maintenance processes

These parameters are:

- “FS conferma ritard.” that is defined as the shift factor for late completion. For example, if the maintenance cycle starts every month and the order is scheduled for the 15th October of 2022 but is completed on the 30th of the same month then, with a value of 25% set, the next cycle of maintenance will start on the 19th November of 2022. If the value set in the field was 100% the maintenance cycle would start on the 30th November of 2022;
- “Tolleranza” is a percentage value used to determine the next occurrence of the cycle. If it is set to 100% the next cycle starts at the time predetermined by the programmed maintenance process; if it is set to 0% the system recalculates the maintenance cycle from the date when the order is closed;
- “FC conferma antic.” that is defined as the shift factor for premature completion and works as the “FS conferma ritard.”;
- “Fattore di estensione” that is the extension factor; thanks to this factor a maintenance cycle can be modified. If it is studied to be made every 60 days, if the factor is equal to 1,1 then it will be done every 66 days, if it is equal to 0,9 it will be done every 54 days;
- “Orizzonte di apertura” defines when the warning to generate the odm must be created. If the value is set to 100% then on the same day of the maintenance order the warning will be generated.

The ZJI2 program is useful to prevent from corrective maintenance processes and to keep the vehicles in a healthy status. These cycles are also implemented in according with the regulations that in some cases require checks and tests on some equipment for safety reasons.

6. Sweepers' case study, failure analysis and KPIs

As seen in chapter [4.1] there are different typologies of vehicles and equipment in IREN Ambiente; the most critical from the maintenance engineering point of view are the sweepers.

Because of their complexity sweepers face lot of problems and critical failures that could lead to important down-times. In this context all the sweepers belonging to the division number 3000, and so the one which are propriety of IREN Ambiente, are analyzed.

There are different kind of sweepers in the fleet:

- little-sized with a hopper lower then 2 m^3;
- middle-sized with a hopper comprehended between 2 m^3 and 4 m^3;
- large-sized with a hopper bigger then 4 m^3.

6.1 Little-sized sweeper: Boschung Urban Sweeper S2.0

The Boschung Urban Sweeper S2.0 belongs to the group of the little-sized sweeper and is fully powered by electric. Two schematic pictures of the vehicle are reported in figure [22].

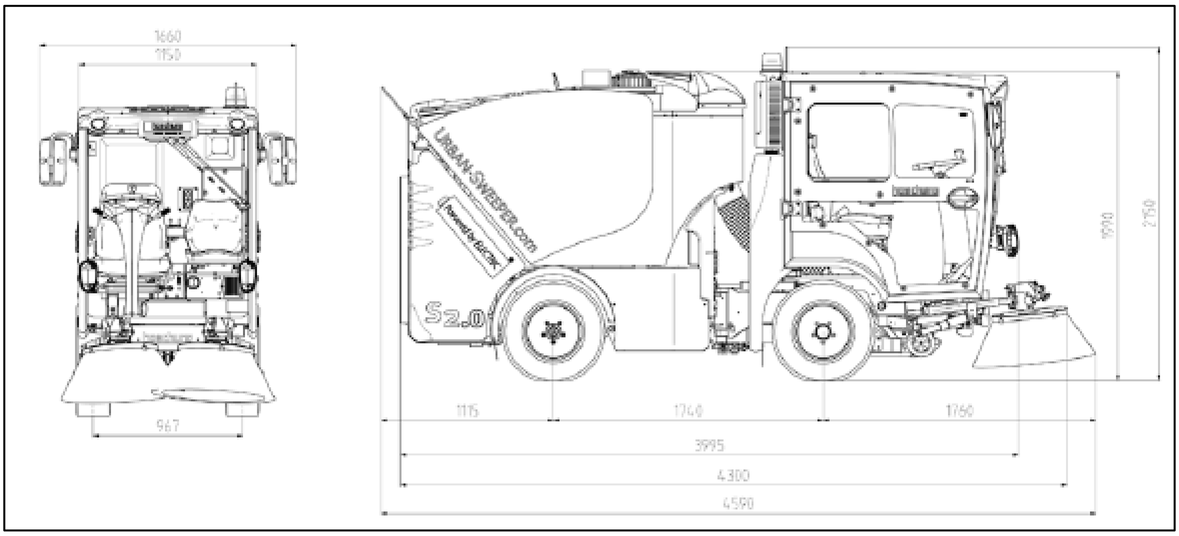

Figure 22. Boschung Urban Sweeper S2.0 [6]

The vehicle is equipped with a high-voltage Li-Ion NCA battery pack operating at 96V. The battery pack is composed by 12 modules with 4320 cells located under the basin of the wastes. The BMS (battery management system), better detailed in chapter 10, determines the charge ratio and the power immitted and extracted from the battery. This BMS receives various information thanks to 24 temperature sensors installed inside the battery pack.

Following the temperature, the BMS will adjust the power of the different motors and the power extracted or inserted in the battery pack [6]. Thanks to this, the battery is always protected from the complete discharge or the overload so that it can last for all its useful life. The electric energy that comes from the battery pack is converted thanks to the convertors and then conveyed to the electrical motors operating in AC that convert the electrical power in mechanical power, allowing the use of the turbines, traction motors, compressors for the air conditioning system, hydraulic pump and the pump of the high-pressure water.

Boschung Urban Sweeper S2.0 is also equipped with a double disk system of brushes with a diameter of 800 m for each one and steel/nylon bristles. The traction motors are two and can provide a power of 20 kW.

The battery pack can power every motor and high voltage system present in the vehicle like the turbine, the brushes, the cooling and warming system, and the traction motors.

For the sweeping, the suction mouth is located behind the two brushes right before a deflector used for the coarse dirt. The turbine that allows the collection of the wastes is activated by an 11kW variable speed electric motor that also has the boost function that allows reaching the 120% of the nominal velocity for 1 minute. The total volumetric flow rate of the turbine is 8500 $\frac{m^3}{h}$.

The water present in the tank allows to moisten the dirt thanks to the nozzle present near the brushes fixing the dirt on the ground for successive sweeping. The water present in the wastes, collected in the waste reservoir, flows through 3 mesh filters directly in the suction tube thanks to a water recycling system. The Boschung Urban Sweeper S2.0 can capture the PM 2.5 and PM 10 for a clean environment and is certified 4 stars.

From the 96V battery pack the power is transmitted to an inverter and then directly to the two traction motors installed on the anterior axis.

The most important characteristics regarding the battery, the traction motors and the fan suction are reported in tables [1],[2],[3]:

Nominal voltage	96 V
Capacity	54,4 kWh
Operating time without charging	>10 h
Number of modules	12
Number of cells	4320
Type	Li-Ion NCA (Lithium – Nickel – Cobalt – Aluminium – Oxide)
Ensured recharing cycles	≈ 7500
Amount of time to recharge with fast charging system	100 min @ 50 kW
Amount of time to recharge with slow charging system	8 h @ 7,4 kW
Weight	312 kg
Dimensions	1580 mm x 600 mm x 508 mm

Table 1. Technical data about Li-Ion NCA for Boschung Urban Sweeper s2.0 [6]

Radial fan	Integrated on the superior part of the tank
Design	Resistive to wear, self-cleaning with inspection door
Maximum volumetric air flow rate	8500 $\frac{m^3}{h}$
Impeller diameter	600 mm
Power	Powered by electric thanks to an AC motor
Nominal power	6,4 kW
Maximum power	11,3 kW
Nominal torque	20,4 Nm
Maximum torque	45 Nm

Table 2. Suction fan technical data for Boschung Urban Sweeper s2.0 [6]

Traction motors located on the anterior axis	2 motors powered by AC
Nominal power	2 x 12 kW
Maximum power	2 x 20 kW
Nominal torque at the wheel	2 x 830 Nm
Maximum torque at the wheel	2 x 1450 Nm
Maximum velocity	40 $\frac{km}{h}$
Payload	1200 kg

Table 3. Traction technical data for Boschung Urban-Sweeper S2.0 [6]

6.2 Middle-sized sweepers: SCHMIDT CLEANGO 500

The SCHMIDT CLEANGO 500 belongs to the group of the middle-sized sweepers. Two schematic pictures of the CLEANGO 500 are reported in figure [23]

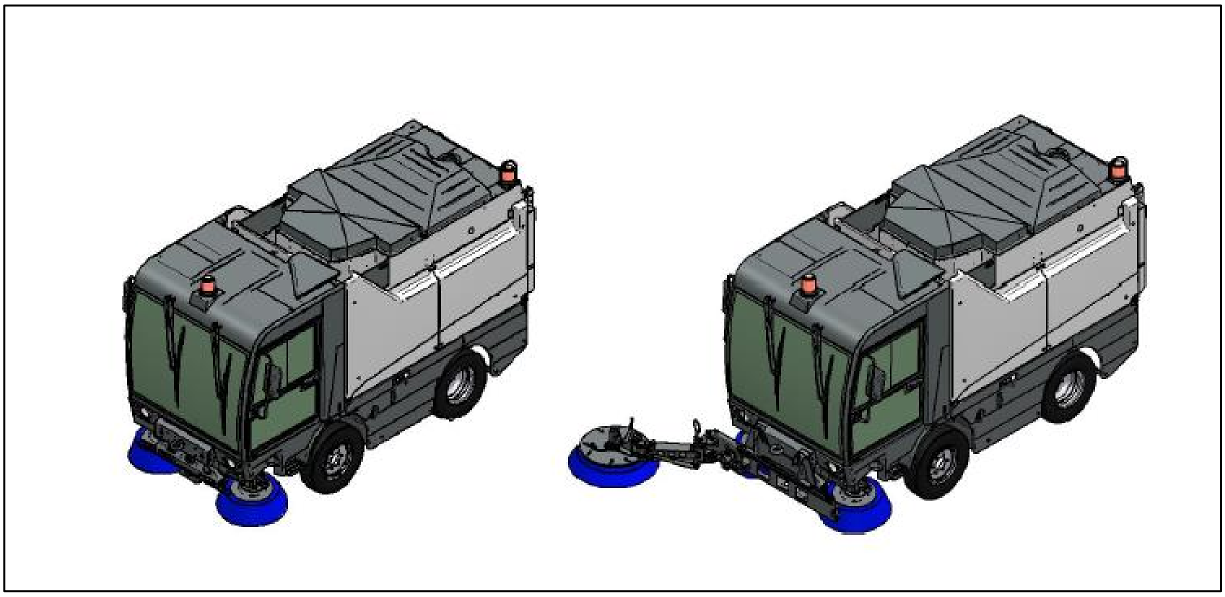

Figure 23. CLEANGO 500 schematic pictures [7]

The vehicle works thanks to a hydraulically driven blower mounted on the top of the debris hopper where a vacuum is generated inside.

The suction created thanks to the blower allows the waste, swept up by the brushes, to flow inside the intake tube that enters the debris hooper. Thanks to the rapid change in volume between the intake tube and the hopper, the air speed slow down allowing the deposition of the materials that was sucked up during the sweeping.

To keep dust under control and also the lighter particles, the debris must be dampened with water. The water jets present in the suction nozzle allows a better deposition of the particles inside the hopper.

The system, certified 4 stars as the Boschung Urban Sweeper S2.0, can capture and control the dusts that are formed during the sweeping since it would otherwise be blown back to the external by the exhaust air system.

The scheme of the dust control system is reported down below in figure [24].

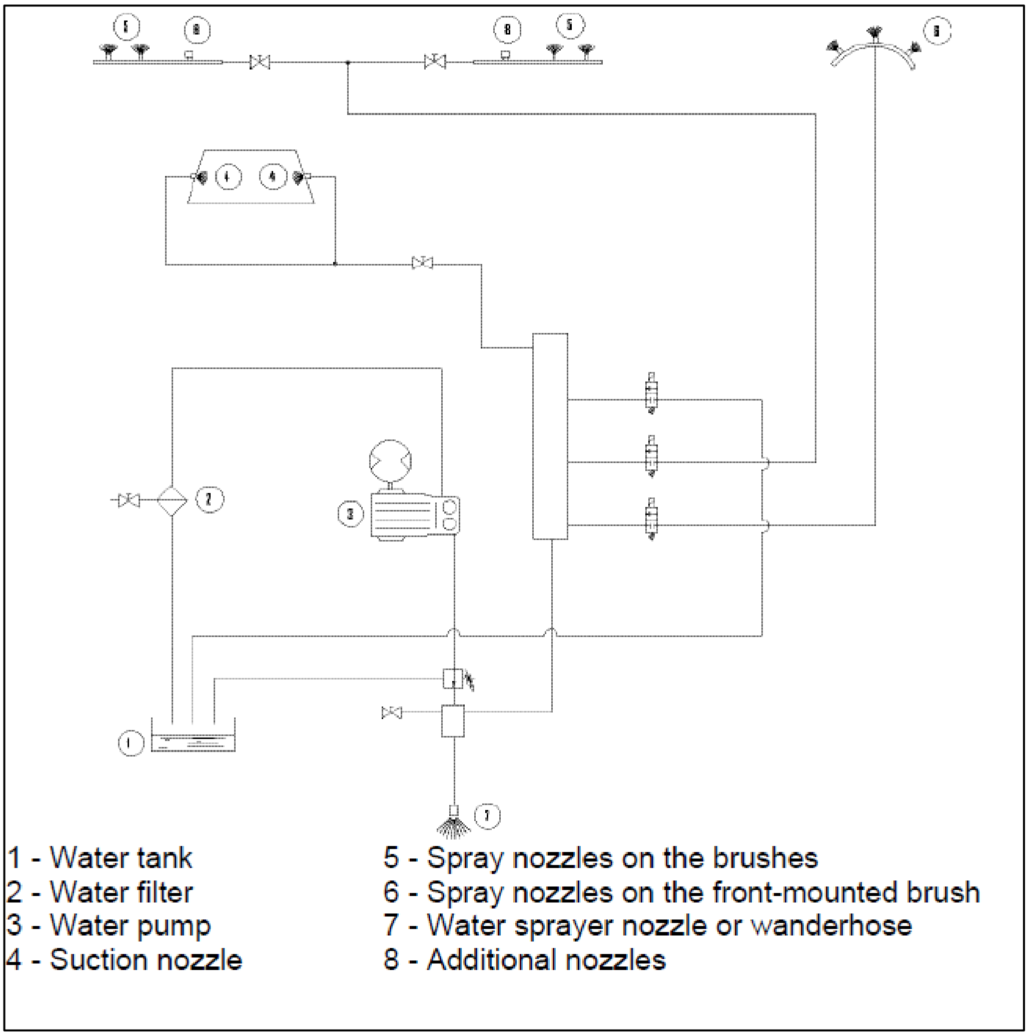

Figure 24. Dust control system for CLEANGO 500 [7]

As shown in figure [24] the water pump supplies the suction nozzle, the sweeper unit, the front-mounted brush, the wanderhose operation and the high-pressure spray wand. Spray nozzles are installed in front of the brushes, in the vacuum opening and the pump supplies them with pressurized water where the actual amount can be regulated depending on the degree of contamination of the road.

The vehicle is reported in figure [25], while a scheme synthesizing the functioning of the vehicle is reported in figure [26].

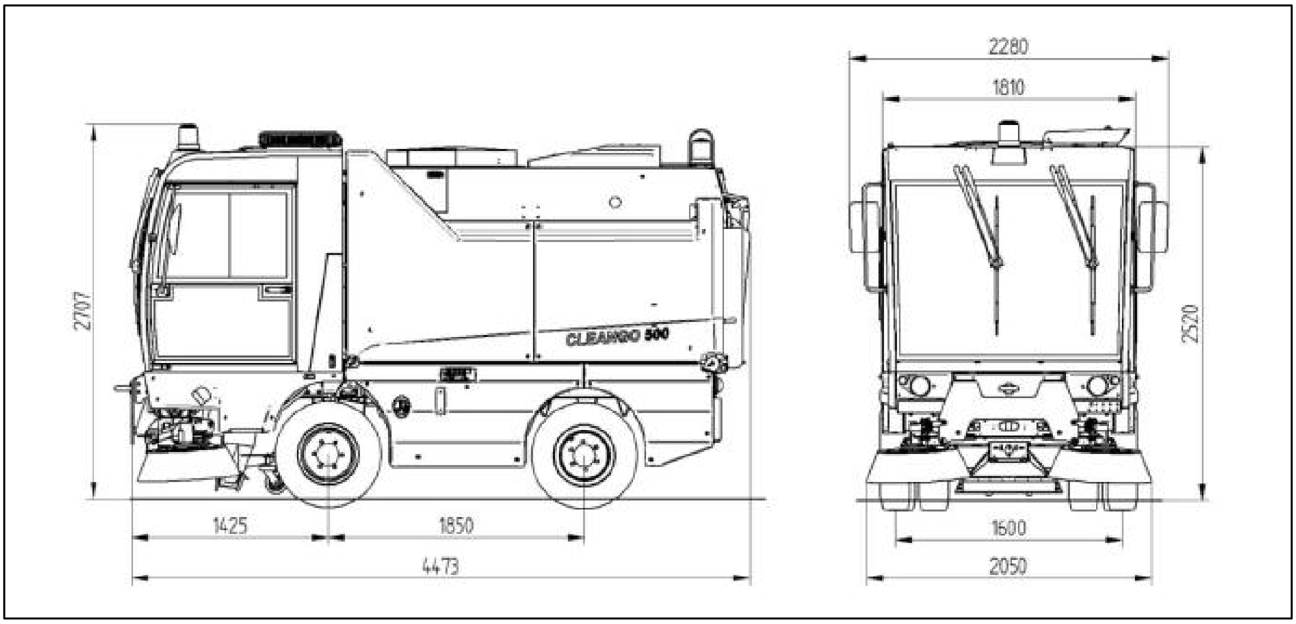

Figure 25. Schmidt CLEANGO 500 schematic picture [7]

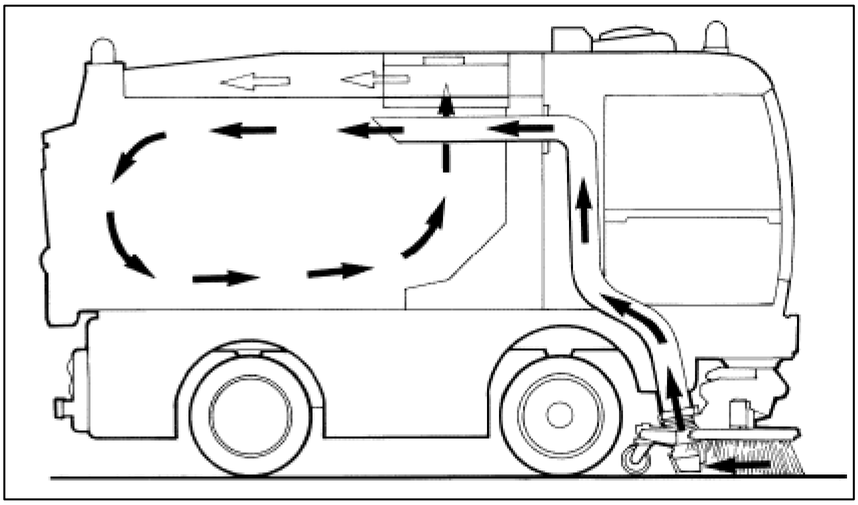

Figure 26. Schmidt CLEANGO 500 functioning cycle [7]

The most important technical data underlines what prescribed in table [4]:

Engine capacity	4,455 cm^3
Maximum power	120 kW
Maximum torque	500 Nm @ 1400 rpm
Rpm during sweeping	1100 – 1700 rpm

Payload	5800 kg
Transfer velocity	40 km/h
Swept velocity	15 km/h
Turbine rpm	3300 rpm
Volumetric air flow rate	14000 $\frac{m^3}{h}$

Table 4. Cleango 500 technical data [7]

6.3 Large-sized sweepers: Dulevo 5000 Veloce

Dulevo 5000 Veloce is one of the most used sweepers in IREN Ambiente thanks to its capability to reach 70km/h, thanks to this, these vehicles can operate in Piacenza, Parma and Reggio Emilia covering also big distances during the year. In these cities, the speed of transfer becomes a really important point to increase the efficiency of the global mission.

A schematic picture of the vehicle is reported in figure [27]:

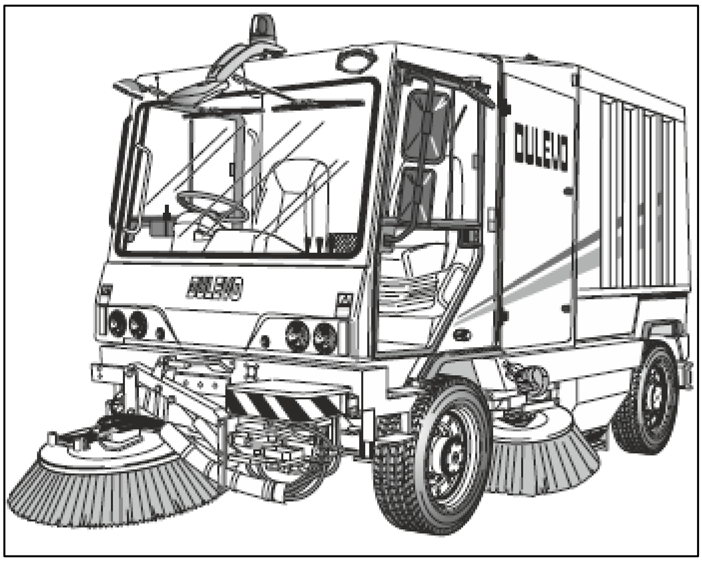

Figure 27. Schematic picture of Dulevo 5000 Veloce [8]

Dulevo 5000 Veloce is equipped with a patented mechanical-suction-filtering system and the collection of the wastes is done mechanically thanks to a system of side brushes that convey the debris toward the center of the machine. Also in this case, different nozzles are present near the brushes and used to facilitate the collection of the dust from the roads.

Another cylindrical brush is present near the central brushes and is used to send the debris to a vertical conveyor that load the refuse tank from the upper part optimizing the loading capacity of the machine. [8]

Thanks to the filtering system and the depression in the wastes tank created by two high-range and high-prevalence suction fans [8] the particulates is retained inside the tank ensuring the reintroduction of only clean air in the environment.

As seen for the Boschung Urban Sweeper S2.0 also the Dulevo 5000 Veloce is certified PM 2.5 and PM 10 and is certified 4 stars also.

The most important technical data are reported in table [5]:

Mass with an operator (70 kg), fuel/hydraulic tanks full, hopper bin empty	8000 kg
Supply	Gas oil
Cooling	Water
Maximum power	152 kW
Working rating	1800 rpm
Transfer speed	0 – 70 $\frac{km}{h}$
Electric system – nominal voltage	24 V
Alternator	90 A

Table 5. Dulevo 5000 Veloce technical data [8]

6.4 Data mining, operation blocks and KPIs

The failure analysis is developed for the sweepers shown in the previous chapters following the data mining reported in the flow chart of figure [28].

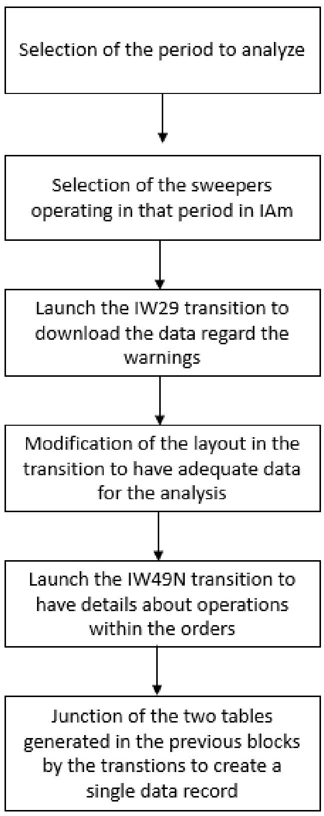

Figure 28. Flow chart operations for the KPIs analysis

In block 1 operations, the period used to perform the analysis is October 2021 – October 2022. The reason why this period was taken in consideration is because IREN Ambiente started to use SAP PM on January 2021; supposing a period of adjustment, October 2021 is selected as the first useful date to start the analysis.

In block 2 operations, the sweepers selected are the one that in the period between October 2021 and October 2022 were operating and were not planned to be sold or dismantled.

In block 3 and 4 operations, the transition IW29 for the visualization of the warnings is launched and the standard layout is modified according to the needs of the analysis.

The information imported in the new layout are:

- serial number of the warning automatically generated during the creation of the warning;
- serial number of the maintenance order associated with the warning;
- date reporting when the warning is created;
- date reporting when the warning is closed;
- typology of the warning;
- description of the warning written during the creation;
- technical headquarters defined in chapter [3.1];
- the "blocking warning" flag;
- the time expressed in the format hh:mm:ss in which the warning is created.

Part of the record extracted from these operations is represented in figure [29].

Warning	Order	Creation Data	Ended data	Warning type	Description	Technical headquarter	Blocking flag	Creation time
5000057113	6000052359	26/05/2022	11/10/2022	ZR	REVISIONE SPAZZOLA DI RICERCA	A-EM-PC-BORG		13:37:55
5000040435	6000036989	10/11/2021	02/02/2022	ZR	RECUOPERO PRESSO BAGNOLO-CORRAD.-R.D	A-EM-RE-GONZ		09:16:05
5000048231	6000044141	14/02/2022	13/04/2022	ZR	MANUTENZIONE PROGRAMMATA 500 H + INTER	A-EM-RE-GONZ		13:29:44
5000059991	6000055000	29/06/2022	25/08/2022	ZR	PRTELLONE POSTERORE	A-EM-RE-GONZ		16:38:21
5000064398	6000059156	25/08/2022	15/10/2022	ZR	Specchio guardaruote mancante in ordine	A-EM-RE-GONZ		13:08:42
5000042724	6000039171	22/12/2021	09/02/2022	ZR	REVISIONE MOTORE NUOVA RECAT	A-EM-RE-GONZ		07:34:50
5000043136	6000039575	28/12/2021	09/02/2022	ZR	GAS DI SCARICO IN CABINA	A-EM-PC-BORG	X	12:36:18
5000060054	6000056877	30/06/2022	11/08/2022	ZR	Perno fuso ruota dx da sostituire	A-EM-RE-GONZ		13:13:08
5000063334	6000058153	10/08/2022	20/09/2022	ZR	MOTORE RUMOROSO	A-EM-PC-BORG		05:07:10
5000050149	6000049071	07/03/2022	14/04/2022	ZR	Melegari Simone	A-EM-PR-BAGA	X	09:58:41
5000050439	6000046260	10/03/2022	15/04/2022	ZR	DA BOLZONI	A-EM-PR-BAGA	X	10:24:34
5000056420	6000051709	19/05/2022	21/06/2022	ZR	SPIA RECOVERI - ESPULSORE <CABIRI>	A-EM-RE-GONZ		08:27:58
5000060380	6000055331	04/07/2022	05/08/2022	ZR	CONDIZIONATORE <RD>	A-EM-RE-GONZ		12:09:45
5000059940	6000054956	29/06/2022	26/07/2022	ZR	Cuffia cassa- RADIATORE-MARMITTA<CABIRI>	A-EM-RE-GONZ		08:38:24
5000037496	6000034246	20/10/2021	16/11/2021	ZR	CONTROLLO GENERALE	A-EM-PC-BORG	X	09:52:12
5000039424	6000036065	12/11/2021	08/12/2021	ZR	LUCANO si spegne mentre va	A-EM-RE-GONZ		12:42:09
5000053330	6000048997	12/04/2022	06/05/2022	ZR	Non va aria condizionata	A-EM-PC-BORG		12:28:52
5000063632	6000058383	13/08/2022	06/09/2022	ZR	FERMA DAL LAVAGGIO	A-EM-PR-BAGA		11:37:22
5000050919	6000046729	16/03/2022	08/04/2022	ZR	AF62 PIATTO	A-EM-PC-BORG		11:12:01
5000057281	6000052529	28/05/2022	20/06/2022	ZR	SPIA ANOMALIA MOTORE	A-EM-PC-BORG		11:58:25
5000064612	6000059351	29/08/2022	21/09/2022	ZR	REVISIONE CILINDRI SOLLEVAMENTO CASSA	A-EM-RE-GONZ		10:06:09
5000054342	6000049880	26/04/2022	18/05/2022	ZR	ARIA CONDIZIONATA NON VA	A-EM-PC-BORG		12:46:06

Figure 29. Part of the record used for the KPIs analysis

In block 5, the customized transition IW49N is launched to have the different information about the coded operations related with the warning. In figure [30] part of the record extracted is reported:

Equipment	Type of Order	Order	Tsto br.	Operazione	Operazione testo breve
601752	ZJI1	6000052359	REVISIONE SPAZZOLA DI RICERCA	0010	REVISIONE SPAZZOLA DI RICERCA
601876	ZJI1	6000036989	SOCCORSO CON RECUOPERO PRESSO BAGNC	0010	SOCCORSO TRAINO E RECUPERO
602735	ZJI3	6000056839	INSTALLAZIONE DISPOSOTIVO ANTINCENDIO	0010	INSTALLAZIONE DISPOSOTIVO ANTINCENDIO
601876	ZJI1	6000044141	MANUTENZIONE PROGRAMMATA 500 H + INTER	0010	MANUTENZ. PROGR. 500 H
601877	ZJI1	6000055000	PRTELLONE POSTERORE	0010	SOST. CERNIERE
601872	ZJI2	6000049027	Man.breveSpazz. C0712	0010	INT. UGELLI UMETTAGGIO
601872	ZJI1	6000059156	Specchio guardaruote mancante	0010	SOST. SPECCHIO RETROVISORE DX
601873	ZJI1	6000039171	REVISIONE MOTORE NUOVA RECAT+VERIFICHE	0010	REV. PARZIALE MOTORE
601795	ZJI2	6000046772	Man.breveSpazz. B2631	0010	INT. UGELLI UMETTAGGIO
601750	ZJI1	6000039575	GAS DI SCARICO IN CABINA	0010	VER. IMPIANTO GAS SCARICO
601876	ZJI1	6000056877	Perno fuso ruota dx da sostituire	0010	INT. PERNO FUSO DX 1°ASSE STER
602552	ZJI1	6000058153	MOTORE RUMOROSO	0010	INT. GENERICO MOTORE
601793	ZJI1	6000034171	Alinovi.s	0010	INT. IDROGUIDA
602466	ZJI1	6000049071	Melegari Simone	0010	SOST. MECCANISMO DI CHIUSURA
601793	ZJI1	6000046260	Alinovi.s	0010	SOST. BATTERIA/E
601873	ZJI2	6000049024	Man.breveSpazz. C0714	0010	INT. UGELLI UMETTAGGIO
601796	ZJI2	6000052436	Man.breveSpazz. B2632	0010	INT. UGELLI UMETTAGGIO
601873	ZJI1	6000051709	SPIA RECOVERI	0010	INT. CENTRALINA ELETTRONICA RESET
601872	ZJI1	6000055331	CLIMA	0010	INT. RICARICA CONDIZIONAMENTO
601795	ZJI3	6000050923	REVISIONE GRUPPO TERZA SPAZZOLA	0010	REV. GRUPPO SPAZZOLA RICERCA
601745	ZJI1	6000034246	CONTROLLO GENERALE	0010	MANUTENZ. PROGR. 500 H
601795	ZJI2	6000046849	Man. Spazzatrice B2631	0010	LUBRIFICAZIONE ALLESTIMENTO

Figure 30. Part of the IW49 extraction record

In block 6, using excel and knowing the maintenance orders associated with the warnings a single data record is generated. In this data record every maintenance order has his operations attached.

At this point the analysis of the different KPIs is performed.

6.5 Technical KPIs and economic KPIs applied to the case study.

According with chapter [2.2] two macro-categories of KPIs are studied, economic KPIs and technical KPIs.

Regarding the economic KPIs defined in formulations (16), (17), (18), (19), (20), (21), (22) they are now rooted in the case study of the sweepers previously described.

$$E1 = \frac{TMC}{AF} = \frac{361645{,}40\ €}{27\ vehicles} = 13394{,}27\ \frac{€}{vehicle} \tag{31}$$

$$E2 = \frac{ICP + IMPC}{TMC} = \frac{150060{,}58\ €}{361645{,}40\ €} = 0{,}415 \tag{32}$$

$$E3 = \frac{CTT}{TMC} = \frac{117601{,}44\ €}{361645,40\ €} = 0{,}325 \tag{33}$$

$$E4 = \frac{TCSP}{TMC} = \frac{93983,41\ €}{361645,40\ €} = 0{,}260 \tag{34}$$

$$E5 = \frac{CCM}{TMC} = \frac{305240{,}17\ €}{361645{,}40\ €} = 0{,}844 \tag{35}$$

$$E6 = \frac{CPM}{TMC} = \frac{29442{,}84\ €}{361645{,}40\ €} = 0{,}081 \tag{36}$$

$$E7 = \frac{CEM}{TMC} = \frac{26962{,}39\ €}{361645{,}40\ €} = 0{,}075 \tag{37}$$

Concerning TMC, it is calculated thanks to SAP PM that for every maintenance order gives the total cost including personnel costs, spare parts costs, and external maintenance interventions costs while AF is well-known thanks to the record of the fleet.

ICP + IMPC, CTT and TCSP are archived on SAP PM, in figure [31] is shown where the costs land on the software.

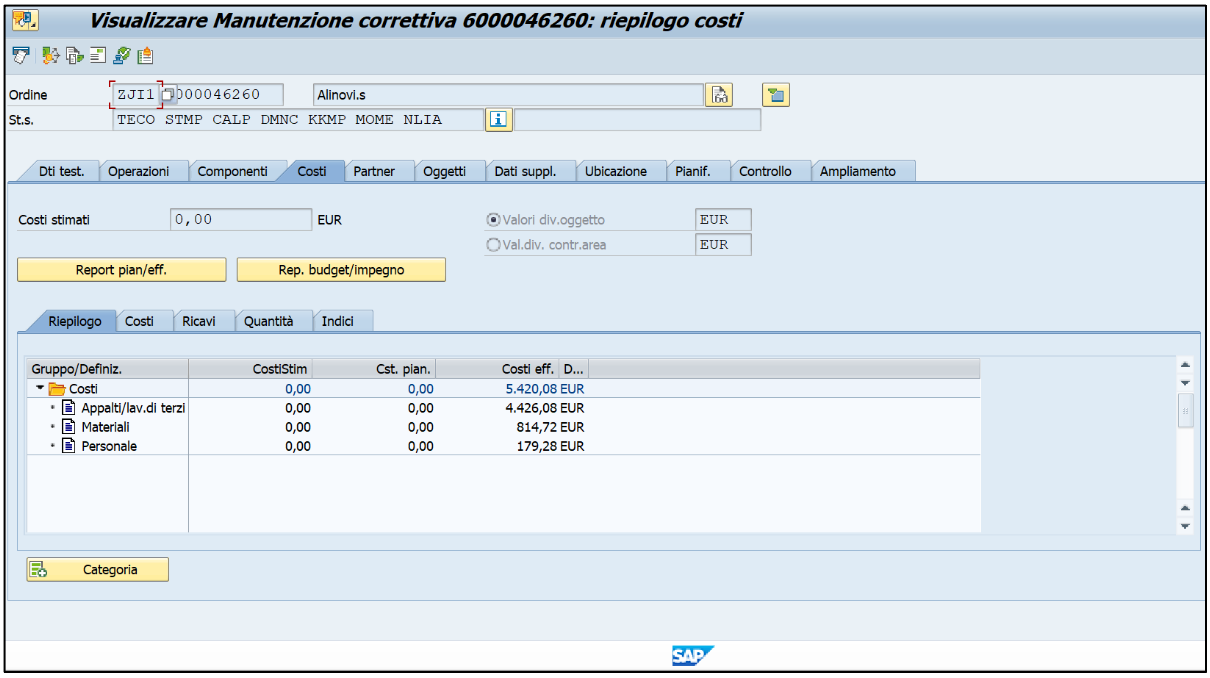

Figure 31. Example of costs summary for an order

The costs above mentioned in figure [31] are filed but are not extractable from SAP PM while the total cost is known and can be extracted from the IW29 transition. The only way to have the costs separated for every order is to use the transition ME2K to visualize the purchase orders done in the period of the analysis of the warnings and maintenance orders.

The external maintenance interventions and the spare parts are always linked with a purchase request. Tracking these requests and knowing the maintenance order as the research key, the purchase orders associated are found.

To understand if an order is related to a spare part or an external maintenance process the filter is imposed on a field where if it is populated it means that the order is associated with a spare part; the field is called “campo materiale”.

Knowing the total costs and the cost of the external interventions and the spare parts, the personnel costs for the indirect and direct part is calculated with the formulation in (38).

$$TMC = (ICP + IPCM) + TCP + CTT \quad (38)$$

About the technical KPIs defined in formulations (23), (24), (25), (26), (28), (29), (30) the calculations are performed for the case study.

$$T1 = \frac{TNAM}{(TTA + TNAM)} = \frac{TNAM}{TT} = \frac{20415{,}47\ h}{300\ \cdot 4h\ \cdot 27\ vehicles} = 0{,}10 \quad (39)$$

$$OEE = \frac{TOT}{TTA} = \frac{TOT}{TT - TNAM} = \frac{53427{,}97\ h}{300\ \cdot 24h\ \cdot 27\ vehicles\ - 20415{,}47\ h} = 0{,}305 \quad (40)$$

$$MTBF_{all\ warnings} = \frac{TOT}{TNF_{all\ warnings}} = \frac{53427{,}97\ h}{1446} = 36{,}95\ \left[\frac{operating\ hours}{warning}\right] \quad (41)$$

$$MTBF_{blocking\ warnings} = \frac{TOT}{TNF_{blocking\ warnings}} = \frac{53427{,}97\ h}{389} = 137{,}35\ \left[\frac{operating\ hours}{blocking\ warning}\right] \quad (42)$$

$$MTTR = \frac{TNAM}{TNF_{blocking\ warnings}} = \frac{20415{,}47\ h}{389} = 52{,}48\ \left[\frac{non\ availability\ hours}{blocking\ warning}\right] \quad (43)$$

$$KTCM = \frac{TTCM}{TTMP} = \frac{18511{,}98\ h}{20415{,}47\ h} = 0{,}907 \quad (44)$$

$$KTPM = \frac{TTPM}{TTMP} = \frac{1812{,}22\ h}{20415{,}47\ h} = 0{,}089 \quad (45)$$

$$KTEM = \frac{TTEM}{TTMP} = \frac{91,27\ h}{20415,47\ h} = 4,47 \cdot 10^{-3} \tag{46}$$

TNAM it's calculated thanks to SAP PM which gives the amount of time needed to solve the order of maintenance while TT it's the total time computed knowing that in a year the working days for the sweepers are, as an estimation, 300 days.

The TOT has been calculated thanks to SAP Waste and the disposal orders recorded in the analyzed period considering as duration the one established by the project department.

MTBF is divided in MTBF for all the warnings (blocking and not) and for only the blocking warnings that block the vehicle from completing its missions.

6.6 KPIs evaluations and interpretation

The KPIs evaluated in chapter [6.5] create a photography that defines in a precise way the management in the maintenance processes in IREN Ambiente for what concern the sweepers.

Economic KPI E1 reports that the maintenance of a sweeper during a year cost around 13394 €. The OPEX for this kind of vehicle includes not only the cost for maintenance processes but also the costs for the fuel and others done to sustain the vehicle for all his life.

As an estimation a sweeper cost 125000 €, knowing that the maintenance processes impact for the 10,71% of the total cost, the target is to lower down E1.

E2, E3 and E4 are related to the total maintenance costs that need to decrease.

One possible solution to reduce the cost of the spare parts could be sign contracts with large part of the suppliers that sell them to IREN Ambiente. The innovation can also have an important role to lower down the costs for the spare parts; for example, in EV vehicles the number of spare parts subjected to wear is lower concerning internal combustion engine vehicles.

The typology of the maintenance process has a role in determining the costs. Maintenance processes entrusted to external workshops are always of the corrective typology. It's preferable to increase the number of preventive maintenance processes, which are always done internally, to face lower quantities of critical failures and, as a direct consequence, lower down the number of interventions done outside IREN Ambiente.

In an ideal condition the KPI E5, linked with the corrective maintenance processes, would tend to be 0 but it's not feasible to have only preventive and extraordinary maintenance processes in IREN Ambiente.

The target is to lower down E5 and increase E6 and the main reason to do that is because the preventive maintenance processes are scheduled to be performed during the hours in which the vehicles are not operating. The corrective maintenance processes, especially the ones linked with blocking warnings that impact on the down-time, usually need more time to be solved and block the vehicles from completing their missions.

The technical KPI T1 underlines that for the 10% of the total time the vehicle was not available; different strategies can be adopted to lower down this value:

- improving the organizations in the workshops following the improvement in chapter [7];
- increasing the number of maintenance processes to lower down the number of failures and, as a consequence, the down-time;
- lower down the time for the supply of the spare parts acting on the contract and deciding the maximum time to send the materials;
- encode the most used destinated spare parts during the year to manage them in the warehouse.

As a target also the OEE should increase but technical limits and an optimal value are possible and function of:

- vehicle characteristics;
- services and missions that need to be completed;
- workshops efficiency;
- typology of failures.

Regarding the MTBF an increase of his value would have good effects reducing the number of failures and the mean time to solve a failure following what prescribed for T1 while for the MTTR a decrease is desirable acting on the overall efficiency of the workshops.

7. Possible improvements for the management of the maintenance order in IREN Ambiente to improve the KPIs

Following the analysis performed in chapter [6] and the evaluations of the KPIs different improvements are suggested to:

- maximize the overall efficiency of the workshops;
- increase the number of preventive and predictive maintenance processes;
- decrease the amount of down-time hours.

7.1 Improvement based on the differentiation of the difficulty of the maintenance operations.

As reported in chapter [6] every maintenance order can have different operations attached. All the operations reported for the various sweepers analyzed are coded and every operation is well-known for his difficulty.

For the operations that need to be carried out to complete the maintenance order, 3 different levels of difficulty can be organized.

Level 1: interventions performed on the external part of the vehicle for those spare parts that are most consumed (for example brushes in case of sweepers).

Level 2: interventions performed on the plants and programmed maintenance processes.

Level 3: interventions performed on the chassis of the vehicle.

Knowing the level of experience of the maintainers, according with their contract levels, they can be assigned with the different operations coded and listed by their difficulties.

Looking at the working contracts five different levels are available in IREN Ambiente:

- Level 1: Maintainers that perform easy operations for which are not requested professional knowledges but a minimum practical period using tools and machines;
- Level 2: Maintainers that perform elementary operations for which are requested general knowledges that can also be acquired after a practical period;
- Level 3: Maintainers that perform executive actions basing on predetermined procedures for which is required professional experience supported by technical knowledges that can also be acquired after a practical period;
- Level 4: Specialized maintainers that perform executive actions for which are required technical knowledges and the application of procedures. These levels of maintainers have the practical and theoretical knowledges acquired thanks to training or equivalent experience and can work also in autonomy;
- Level 5: Specialized maintainers that perform activities for which are required theoretical knowledges that come from higher-degree education or obtained thanks to trainings. They can also coordinate other maintainers and can work in autonomy.

This improvement can be important with a view to maximize the efficiency of the various workshops. An example is down reported.

Supposing a situation in which 2 sweepers are stopped from working, each one with one different kind of failure, and two maintainers, level 1 and 3, available to work.

The first sweeper needs the substitution of the right and left brushes while the second one needs operations on the electrical plant. At present, the workshop manager basing on his knowledge of the two maintainers, assigns the work to do.

It could be an interesting option to create a user interface where:

- the number of the maintainers available in that moment is listed according with their different levels;
- thanks to SAP PM, all the maintenance orders are listed.

To organize the work for the actual day the interface can suggest to the workshop manager an association of the operations with the maintainers following this scheme:

Level 1 and Level 2 maintainers can do Level 1 operations with the exception for level 2 maintainers that can also do level 2 operations if supervised by a level 3 (or more) maintainer. This system can be applied also for level 3 maintainers giving support to perform level 3 operations.

In figure [32] is reported how the process should be structured.

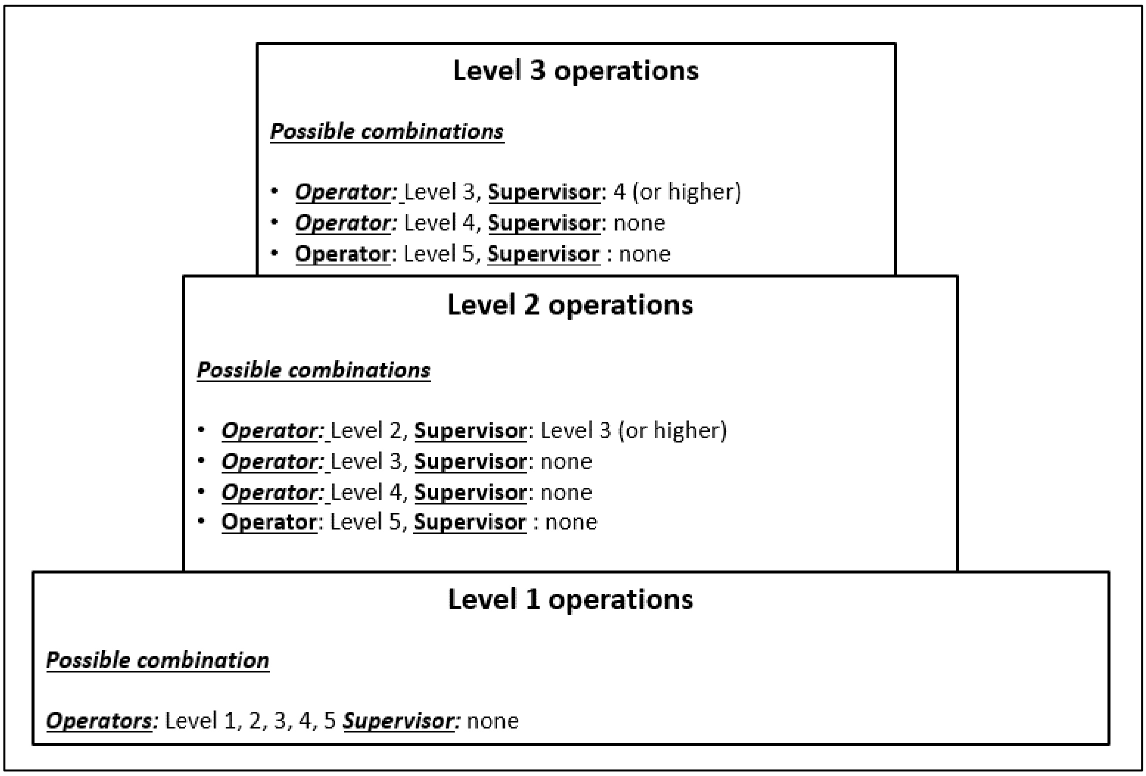

Figure 32. Pyramid operations scheme

This structure can also help to:

- improve the maintainer's skill in working in groups;
- help the different maintainers to implement their know-how;
- encourage the maintainers to participate in the operations where they are not already skilled.

Knowing which vehicles are stopped from work and the people available in the workshop, a first automatic schedule can be done, according with what prescribed before, and modified by the workshop manager.

At the end of the day for every maintainer a record of the operations done in the day is automatically created and for every coded operation completed a counter is present. This counter can report the number of times a maintainer has done a certain operation helping to keep track of the know-how assimilated.

When the counter reaches a certain number, for the operations performed if supervised, the maintainer can be proposed for a job promotion.

Creating an environment where the maintainers are encouraged to work together and also in difficult operations can be important for both IREN Ambiente and the workers.

7.2 Improvement based on remoting Kms, PTO hours and engine hours for maintenance processes

It could be helpful if the most recent vehicles can be equipped with an OBC (on board computer) or equivalent device able to remote the data about:

- numbers of Kms traveled;
- number of PTO hours;
- number of hours in which the engine is on.

Thanks to this, the different measuring points present on SAP PM can be filled and refreshed with the new values every 24hours thanks to a .csv file produced by the OBC.

At this point there will be two possibilities to manage the different maintenance orders in IREN Ambiente:

- manage the preventive maintenance orders on SAP PM;
- manage the predictive maintenance orders on a different support.

Regarding the preventive maintenance orders they can be set to work on the numbers of kms traveled and on the number of PTO hours, when one of the two fields reach the threshold value a warning could be created with also an anticipation of a certain percentage of time concerning real moment in which the value is reached.

About the predictive maintenance processes an external support should be used; regarding this let's suppose a system able to track different data.

Looking at the brushes of the sweeper analyzed in chapter [6] it could be possible to implement a system able to advise the workshop manager about the possibility to do an operation right before the failure happens.

Looking at the reality of IREN Ambiente it's a good estimation to state that the brushes of a sweeper lasts 50 hours, using the concept of predictive maintenance, the workshop manager should be advised to do the substitution of the brushes at 45 hours of work.

A real application of this improvement is reported down below.

Supposing a situation in which a sweeper is stopped from work because of a failure related with the electrical plant of the vehicle. First of all, a warning will be created from the driver that will require the evaluation of the vehicle.

As seen in chapter [4], the vehicle will be evaluated by the workshop manager that assigns a maintainer to the vehicle to proceed with various checks and tests.

After the evaluation, if a maintenance order needs to be created, an interface linked with an external portal could be opened suggesting the possible predictive maintenance operations following the data tracked by the OBC.

An example on how to implement and create the system is reported thinking that for every equipment present in the fleet the data about kms and PTO hours are remoted.

1) A first phase in which a data collection is performed is needed. In this phase every operation is registered. Associated with every operation done within the maintenance order the details related with the number of kms and the number of hours of PTO are collected.
2) After six months the arithmetic mean of the km and the hours of PTO are calculated knowing the two data between each maintenance order and so the difference in time between two maintenance orders. In this step the most important operations, that impact most in terms of down time and repetitiveness, are coded.
3) In the successive six months the arithmetic mean calculated for the coded operations is implemented in the system that, when a corrective maintenance order is required, will suggest the predictive maintenance processes to do if reached the value set.

For the sweeper present in IREN Ambiente a gaussian distribution is reported for the maintenance orders created in the period between October 2021 and October 2022. A number of 1446 maintenance orders were analyzed knowing:

- the date in which the maintenance order was created;
- the date in which the maintenance order was closed;
- number of equipment;
- kind of maintenance order;
- number of days to complete the maintenance order;
- operations to complete the maintenance order.

The maintenance orders analyzed in this phase are linked with a blocking warning that stops the vehicle from completing its missions.

Looking at the gaussian distribution reported:

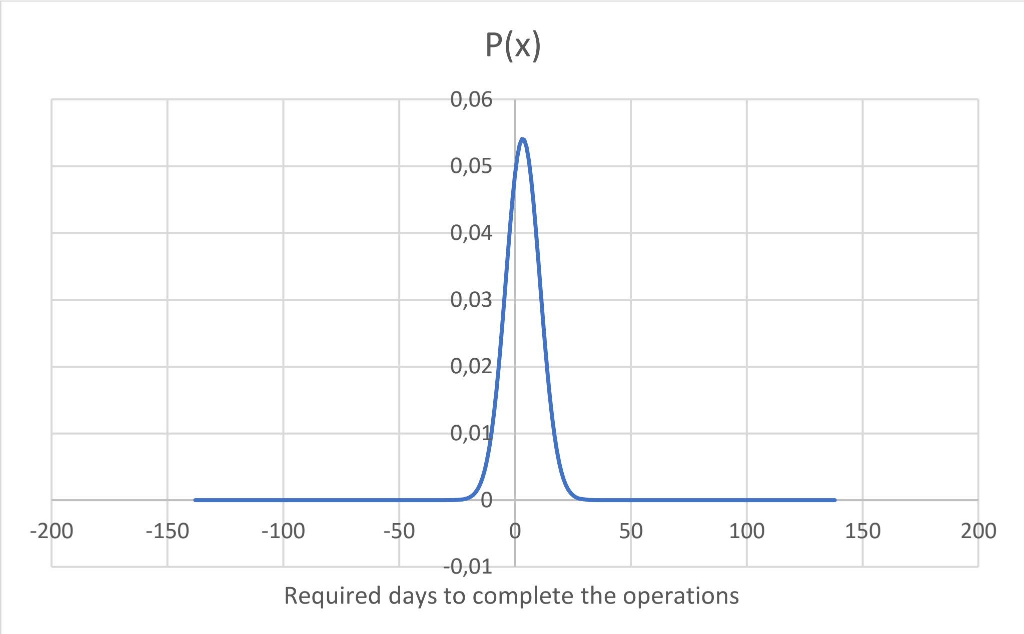

Figure 33. Gaussian distribution for maintenance orders on sweepers

Is visible that most of the maintenance orders are solved in 3 days. It could be useful to develop a case study in which the maintenance orders associated with a down-time higher than 3 days are studied.

For every operation that implies a down-time higher than 3 days the number of times in which it is repeated is counted and, knowing also the equipment associated and the data of creation of the maintenance order, the frequency (daily, weekly, monthly...) of the operations is calculated.

From the analysis the three most impactful operations in terms of downtime and frequency for sweepers are:

1) interventions on the nozzles plant;
2) interventions on gasoline filter;
3) interventions on the research brush.

These interventions, following the analysis performed between October 2021 and October 2022, are usually made:

1) every 3 months for the first operation;
2) every 4 months for the second operation;
3) every 3 weeks for the third operation.

If a system able to remote the km and the PTO hours is available a similar analysis can be performed registering not only the data in which there is the actual creation of the maintenance order but also km and PTO hours.

As an improvement, a predictive maintenance process can be implemented taking these 3 operations as the most impactful.

After a first step which last 6 months, a record of different operations and the 3 tracked before is created reporting:

- number of equipment;
- operation done within the maintenance order;
- number of km and PTO hours

Following this step for every piece of equipment will be possible to compute the difference of kms and PTO hours between two maintenance orders that have the same operation performed.

For the three operations suggested before, these data will be collected and using the external support explained before an interface for the workshops of the business unit can be implemented in the way reported in the next chapter.

7.3 Predictive maintenance interface

As seen in chapter [7.2], after the first phase, the most impactful operations are coded and well-known in terms of frequency.

For every corrective maintenance process that the workshop needs to elaborate the workflow is reported down below following the example in figure [34].

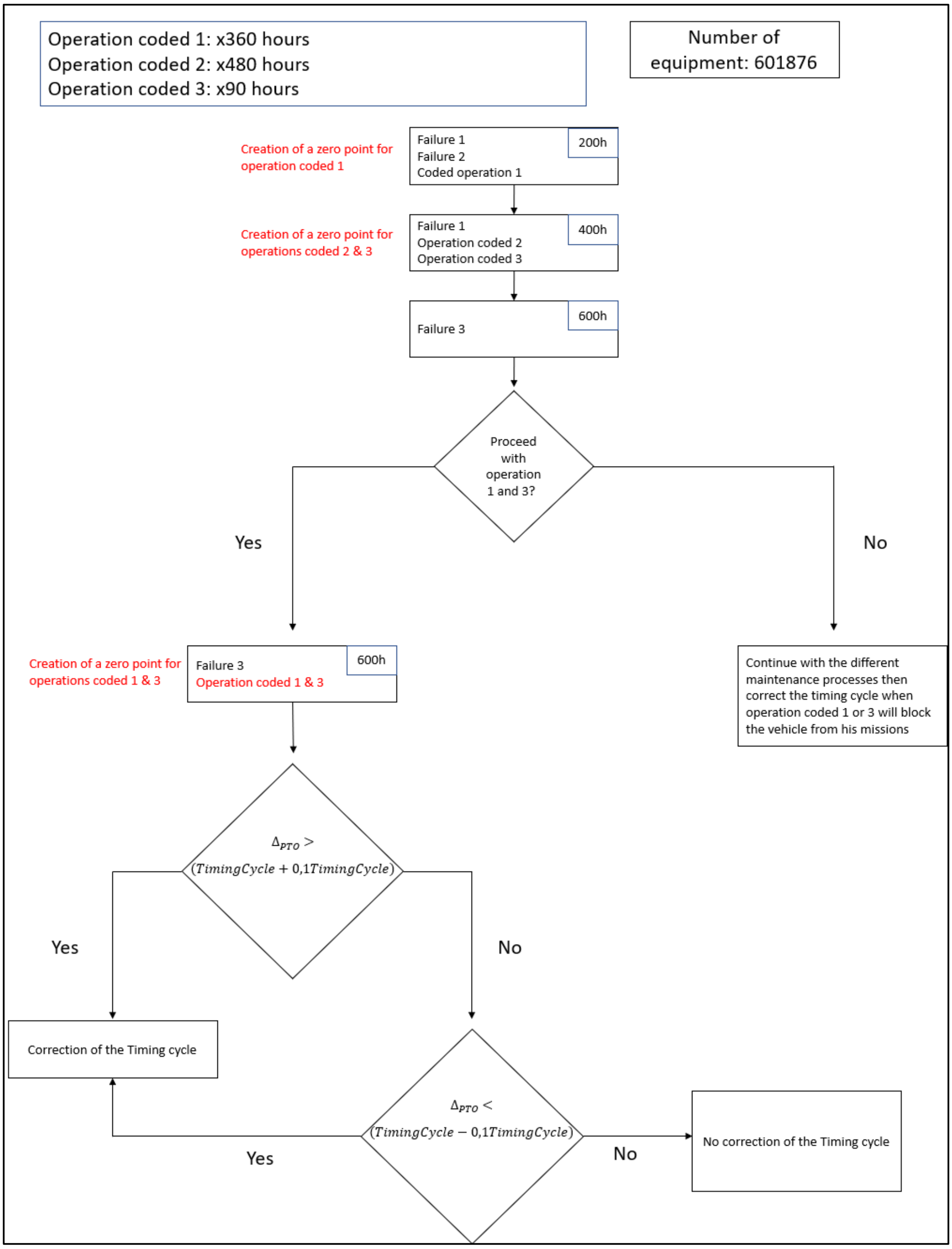

Figure 34. Flow chart for the predictive maintenance

The different rectangles identify maintenance orders and inside each of them different operations are reported. The first one is done when the vehicle has 200 PTO hours and for this one the coded operation 1, which was stopping the vehicle from work, is performed together with failure 1 and 2 operations.

The system in this case will create a "zero point" for operation coded 1 and will start to count, for this specific operation, 360 hours. Failures 1 and 2 are registered following the procedure prescribed at the point 1 and 2 of chapter [7.2] to create an historical archive.

The second rectangle reports failure 1 and the other two coded operations that, as done for coded operation one, will generate two zero points respectively for operations coded 2 and 3.

The next maintenance order reports another new failure and no other interventions. As we can see from the counter more than 360 hours are passed until the last time that operation coded 1 was done and more than 90 hours for operation coded 3. The system can suggest the operation to the workshop manager that can do or not the intervention.

If the workshop manager decides to do the operations a new zero point will be created by the system recording the number of PTO hours passed from the last maintenance order where the coded operations were done. If the operations are not performed, or only one of them is done, the new zero will be created when the vehicle will be stopped from its missions because of the failure linked with the operations avoided before. Again, a zero point will be created.

If the Δ_{PTO} defined as the number of hours between each maintenance order where the coded operation was performed, is higher than his value plus his 10% then the mean calculated in phase one will be recalculated adding one data to the ones of the previous record that was useful to calculate the timing cycle. If Δ_{PTO} is lower another test is done according with formulation (47).

$$\Delta_{PTO} < (TimingCycle - 0{,}1 \cdot TimingCycle) \tag{47}$$

With this system, after a certain amount of time, the value that suggests when to do the various interventions will tend to be the most reliable one for all the coded operations.

The advantage to do predictive maintenance operations are:

1) act before critical failure that can be prevented by doing coded operations;
2) organize the work to don't stop vehicles from their missions;
3) lower down the number of reserves.

If the vehicle has 650 hours of PTO, and the last time the predictive coded operation 1 was done was at 100 hours of PTO, it could be possible that on the next days there will be a critical failure that will impose the maintainers to stop from their work to repair it as soon as possible.

To improve the scheduling of the jobs in the various workshops of IREN Ambiente another improvement is reported in chapter [7.4].

Applying the concepts of predictive maintenance it will be possible to:

- reduce the number of critical maintenance orders acting directly at the source, right before other failures can be generated from the one that can be solved predictively;
- lower the downtime of the vehicles doing the predictive maintenance processes in between the various work shifts allowing a better scheduling of the operations;
- incrementing the efficiency of the maintainers;
- creating a database of the different operations that will be refreshed for every maintenance process.

7.4 "Down-time Report"

In October 2022, a purpose done by me and the administration fleet was to create a document able to communicate as fast as possible the situation of vehicles stopped from work.

The document has the following scopes:

1) being a useful support for the workshops part of IREN Ambiente for a correct scheduling of the jobs according to the vehicles that have the priority to be repaired;
2) give a visual and numerical indication of the deficit and surplus of vehicles useful for covering their work shifts and so their missions;
3) be available for consultation in a constant way with a temporal refresh not higher than 5 minutes.

Regarding point 1, the vehicles that have the priority to be repaired can be identified as the ones that belong to a particular typology for which the personnel who schedule the services for the cities require assistance.

The document will be articulated using an informatic interface where it will be possible to select the working center, the work shift and the date. The result of the selection will be organized in the way reproduced in figure [35].

CdL	TOI30GG
Turno	01_mattina
Data	05/10/2022
Ora	12:21

Codice di gruppo	Descrizione codice di gruppo	Mezzi totali assegnati	Mezzi disponibili	Mezzi indisponibili	Mezzi previsti	Delta
WV-AAL30AF	COMP.BIL.PES.FUNGO	8	7	1	7	0
WV-BAN30QA	QDRCCL.N.U.ELET	15	13	2	14	-1
WV-AAP20AF	COMP.POST.LEG.VETRO	19	19	0	17	2

Dati aggiornati al 05/10/2022 alle ore 12:21

Figure 35. Down-time report interface

In the columns the field populated are:

1) “Codice di Gruppo”, this code identifies the typology of vehicle as explained in chapter [2.1];
2) an extensive description of the “Codice di Gruppo”;
3) the total number of vehicles assigned to the working center previously selected in the moment in which the document is being visualized;
4) the number of vehicles available;
5) the number of vehicles not available;
6) the number of vehicles provided for covering the work shift;
7) the Δ (and so the difference) between the number of vehicles available and the number of vehicles needed to covering the work shift.

There is a particular interface between SAP PM and SAP WASTE that filters the vehicles available for the services and so available to complete their jobs. This interface act as a filter for the vehicles that has a blocking warning assigned or for the one that soon will be estranged.

The number of vehicles available and not available come from the interface that gives these quantities.

For the voice number 5 can be useful, operating directly on the report, to have the details about the number of vehicles not available to have a list of these ones and their equipment number with the possibility to visualize the maintenance orders and the warnings attached to the vehicles.

It is important that, if the consultation of the document is done before the actual date, the data are historicized.

As seen in figure [35], to facilitate the reading of the document it’s requested that:

- if there is a surplus of vehicles, the cell in correspondence with the delta is colored in green;
- if there is a deficit of vehicles, the cell in correspondence with the delta is colored in red;
- if there is an equality between the available vehicles and the one requested by the services, the cell in correspondence of the delta is colored in yellow.

The document will be then readable and consultable by:

1) workshops managers;
2) shift supervisors;
3) administrative staff operating on SAP PM;
4) coordinators of the services.

It is also useful to create a cell filled with the quantities of vehicles that has a similar “CODICE DI GRUPPO” with the one analyzed and so has the same “CD_UNI” explained in chapter [2.1].

8. Adaption of the maintenance processes on vehicles according to the green transition

IREN Ambiente has the target to have an entire green vehicle fleet in 2030. This involves the creation of a maintenance structure able to cope with new maintenance processes from which there are no historical data.

In 2030 all the vehicles present in the fleet will be powered by electricity and methane. At the moment, in 2022, the electric vehicles in IREN Ambiente are: 357.

The architecture of the vehicles powered by an internal combustion engine motor is different from the one of the electric vehicles; for this reason, the maintenance processes need to be adapted to mitigate possible injuries during the maintenance operations.

The procedures that will be applied to the maintenance processes are taken in according:

- UNI EN ISO 9000;
- UNI EN ISO 9001;
- UNI EN ISO 14001;
- BS OHSAS 18001;
- D.Lgs. 81/2008;
- D.Lgs. 152/2006;
- Norma CEI 11-27:2021.

All the workshops of IREN Ambiente have the responsibility to:

- set up the annual plan for the maintenance processes on the electric vehicles;
- guarantee that the maintenance operations are done safely;
- do the preventive maintenance processes and the corrective maintenance processes;
- oversee and manage the activities done by the contractors.

For the execution of electrical works the CEI norm 11-27:2021 defines different working figures:

- PAV: Worker, of any level, that has the basic theory but not sufficient experience in the operative context where IREN Ambiente operates. PAV is a person correctly advised from PES and can carry on some works disconnected from the power supply or near the location as prescribed by the norm;
- PES: Worker, of any level, that has the basic theory and the experience to carry on electrical work within the operative context of IREN Ambiente. PES can do electrical works.

The performance of maintenance processes on IREN vehicles that involve electrical works, as defined by the norm CEI 11-27:2021 even if carrying out by internal or external personnel will be subjected to certain conditions as follows.

For the “enabled maintainers” both in case of electrical works performed in the internal or external workshops, in case the resource is qualified as PES, PAV or PEI form his employer, this information must be communicated in the contract or in the DUVRI if necessary.

For the “non-enabled maintainers” in case, the supplier doesn’t have qualified maintainers enabled to carry out electrical works, every business unit of IREN will assign one of its PES employees that will evaluate if it is necessary to supervise the operations as defined by the chapter 3.7.13 and 3.7.14 of the norm.

In all the cases every maintenance process performed on vehicles or equipment of IREN Ambiente must be done, where possible, in a situation of minimal residual electrical risk characterized from the execution of the operations off-voltage.

Every maintenance process must be done in an appropriate area previously localized in every workshop. These areas will be easy to localize clearly and protected using barriers to avoid unauthorized access from people not able to perform electrical works.

In particular, to have a workshop able to guarantee the right performance of maintenance processes on vehicle or equipment powered by electricity every workshop must:

- have a number of isolated tools equal to the number of the maximum stations that can work simultaneously on electric vehicles or equipment;
- have mobile barriers with the characteristic to be easy to locate to avoid the entrance for people not able to do electrical work;
- have a correct number of collective personal protective equipment at disposal of the maintainers; isolated carpets and isolated platforms are necessary in every workstation and also dielectric helmets with an under-throat belt are necessary;
- have an adequate number of tools able to do electric measurements subjected to regular checks;
- have an adequate number of warning sign to locate the areas used for maintenance processes on vehicle or equipment powered by electricity.

The evaluation of the risk and, as a consequence, the presence of a PES is always mandatory even if a lot of operations are done with the voltage disconnected and are defined as routine operations which are tests and checks.

For the operations of corrective maintenance due to accidents and in general for all the situations in which the conditions of the vehicle or equipment are different from what prescribed in the maintenance documentations given by the constructor, it’s required the presence of the PES that, in the case of impossibility to repair the vehicle, will send the vehicle to an external workshop equipped for the operations needed to repair the item.

In case of traffic accident, the driver will act following the highway code for the emergency stop, will communicate the event and the status of the vehicle and if necessary, leave the vehicle. At this point the service managers will activate the workshop function basing on what planned by the specific company regulations.

The use of an external workshop able to process the corrective maintenance processes is required also for the vehicles in which are not available systems for the exclusion of the power source (traction batteries) from the rest of the electrical circuit.

For the protection of the workers there are specified protective equipment for the electric risk:

- insulated tools;
- insulated gloves;
- insulated platforms or mats;
- clothing to protect from electric arc.

These protective equipment can be used in combination in according with the typology of operation.

In case of vehicle and equipment in which the absence of electric risk is not established, the target is to realize a double layer protection in the direction of the active parts that require the intervention.

Other protective equipment that needs to be used following what established by the maintenance documentation produced by the constructor or specific operative instructions are:

- separation barriers;
- insulated polyvinyl bags with adhesive closure for the protection of the connectors;
- adhesive and/or monitor signs;
- locks and/or other tools used to prevent the rehabilitation of the traction batteries.

Regarding the corrective and preventive maintenance processes there are different risks related with electrical works:

- electric shock;
- electric arcs.

In case of road accident also dangers due to harmful substances and spills of flammable liquids or thermal runaway of the LIB batteries are possible.

To avoid possible accidents and to maintain the level of risk under the acceptance threshold is mandatory the presence of a PES who will provide to execute the following operations:

- make sure that the work zone is correctly identified, bordered and protected;
- consult and respect the warnings referred to the security, the instructions for use and maintenance given by the constructor and the operative instructions;
- section the batteries of the basic electric plant present in the vehicle;
- if possible, section the batteries of the traction plant;
- for both systems take the necessary actions to prevent the reintegration for example using a lock;
- disarm the connectors of the traction batteries and use the insulated polyvinyl bags with adhesive closure or equivalent;
- wait for the discharge time of the active components as indicated on the manual of the constructor;
- verify the absence of voltage using the proper instruments for the measurements;
- apply monitor signs on the vehicle to warn people about the electrical work.

To identify the failure and the possible maintenance operations a person qualified as PES is necessary; he will use:

- the maintenance manual given by the constructor;
- the possible historical data present in SAP PM;
- the diagnosis system present on the vehicle.

9. Analysis of the energy needs for the electric fleet in 2030 and sizing of the charging points for AMIAT

As previously mentioned in chapter [8], IREN Ambiente will have an entire green fleet in 2030 with one part of vehicles powered by methane and the other one by electricity. Also vehicles powered by hydrogen could be an option if consolidate technologies will be present on the market.

A decision made by the business unit is to buy large part of vehicles equal or under the 3,5 ton powered by electricity and the heaviest one powered by methane even if there will be vehicles with a GVM equal to 22 ton, considered as LIFT, that will be electric.

This decision is made basing on the fact that electric vehicles with a weight higher than 3,5 ton require big storages and so absorb more electricity from the grid.

A big storage requires more time to be filled and probably not all the heavy electric vehicles will cover two work shifts within the same day without charge.

The analysis is performed thinking that every 8 years, as suggested by Arera, there will be a replacement of the vehicle, indeed not all the new acquirements will increment the total number of electric vehicles because some of them will be already powered by electricity.

The industrial plan for AMIAT, one of the societies controlled by IREN Ambiente, with the typology of the vehicles and the relative numbers of those that will increment the green fleet is reported in figure [36]. In the period between 2017 and 2020, 316 quadricycles were bought and are reported in the column named "Actual state in 2022".

Typology of electric vehicle	Actual state in 2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Quadricycles	316	12	15	15	15					**373**
Refuse collection vehicles with open top equipment			16	30	15		26		35	**122**
Minicompactors with open top equipment			15					16	6	**37**
Heavy vehicles		2	2	2	2	2	2	2	2	**16**
Little sized sweepers	2									**2**
Middle sized sweepers					6	6	5	5		**22**
Large sized sweepers								3		**3**

Figure 36. Electric vehicles acquisition plan until 2030

The first typology of vehicles, quadricycles, is reported in figure [37]:

Figure 37. Goupil G4 [9]

This vehicle is called Goupil G4 and is used for manual sweeping. The wastes collected by the driver are deposited inside a basin on the vehicle and then transported to the waste deposit.

The Goupil G4 can charge at 3,7 kW in AC at maximum rate power and has a storage of 14,4 kWh made of $LiFePO_4$batteries that ensure a medium range of 143 km. This vehicle is part of the category “under 3.5 tons”. [9]

In 2022 the Goupil G4 presents in the fleet are 316 in AMIAT, 15 in IAm, 2 in ACAM La Spezia and 2 in ASM Vercelli but until 2030 others will be bought to substitute the petrol version but also the electric one that for that time will be too much old.

In the Goupil G4 the LIB batteries power an asynchronous induction motor operating at 48V expressing a nominal power of 10 kW.

For the typology of vehicle 2 and 3, vehicles will have a GVM (gross vehicle mass) equal to 3,5 ton. Three vehicles, with the characteristics desired by IREN Ambiente and Amiat, are identified. These vehicles are branded by Foton, Maxusus and Goupil.

The calculations of the energy needs are done thinking that the Foton IBlue T5 full electric will be selected from the different vehicles listed before. The characteristics of the Foton T5 IBlue are reported in table [6] and a picture of the vehicle is reported in figure [38].

GVM	4250 / 6000 kg
Payload	1780 / 3530 kg
Driving mileage per charge	208 km
Type of battery	$LiFePO_4$
Methods for cooling (traction battery)	Liquid cooling system
Capacity of the battery	81,14 kWh
Voltage	540,96 V
Charging mode	AC / DC
AC charging power	11 kW
Charging time SOC 20% - 100% (normal temperature)	1 h / 7 h
Motor type	Permanent magnet synchronous motor
Rated / peak power	60 / 100 kW
Rated / peak torque	450 / 1000 Nm

Table 6. Foton Technical data [10]

Figure 38. Foton IBlue T5 [11]

For the typology of vehicle 4, heavy vehicles, present in figure [39], the VOLVO FE 6X2 is one of the most interesting for the needs of IREN Ambiente and AMIAT. This vehicle has an electric motor of 400kW and 4 Li-ion NCA batteries operating at 600V with a total storage capacity of 265kWh. VOLVO FE 6X2, can charge at 22kW/AC and 150 kW/DC. [12]

Figure 39. VOLVO FE 6X2 [12]

For the little sized sweepers, the vehicles are already present in 2022 and are identified as the Boschung Urban Sweepers 2.0, these vehicles are classified as 2 m^3 as explained in chapter [6.1]

The vehicle can be charged using a standard charger operating in AC in 9 hours or with a supercharger charging in DC in 2 hours following what described in the user manual.

The other two typologies of sweepers listed in figure [36] are the middle-sized and the big-sized. The SCHMIDT E550 and the RAVO 540 Electric are identified as middle-sized sweepers while for the big sized no information are available at the moment.

The technical data of the SCHMIDT E550 are reported in table [7] for two configurations of vehicles with 2 and 3 brushes.

	eCleango 550 | 2-brush system	eCleango 550 | 3-brush system
Tank Volume	5,5 m^3	5,5 m^3
Fresh water volume	750 l	750 l
Total capacity	100 kWh / 400 V (Option: 150 kWh /400 V)	100 kWh / 400 V (Option: 150 kWh /400 V)
Torque traction drive (rear axle)	135 – 350 Nm	135 – 350 Nm
Power traction drive (rear axle)	140 kW	140 kW
Transport speed	25/30/35/40/45/50 $\frac{km}{h}$	25/30/35/40/45/50 $\frac{km}{h}$
Payload	5300 kg	5300 kg

Table 7. eCleango 550 technical data [13]

At this point knowing the total numbers of vehicles per typologies and the vehicles that will substitute the electrical versions and the petrol version within the 8 years it is possible to estimate the number of electrical vehicles in AMIAT.

There are two ways to charge the vehicles: using AC or using DC.

Two different charging scenarios are studied knowing also how much are the vehicles that will be substituted in 2030 are assigned in the different working centers of AMIAT.

Knowing how the vehicles are distributed all over the working centers the same distribution is maintained until 2030 in the assignation of the new vehicles.

The results of the analysis knowing the number of vehicles for all the working centers and the energy needs in the charging phase of the various typologies of vehicles are reported in figure [40].

Typology of electric vehicle	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total	AC [kW]	DC [kW]	Total AC [kW]	Total AC/DC (where available) [kW]
Quadricycles	316	12	15	15	15					**373**	3,7		1380,1	1380,1
Refuse collection vehicles with open top equipment			16	30	15		26		35	**122**	11	50	1342	6100
Minicompactors with open top equipment			15					16	6	**37**	11	50	407	1850
Heavy vehicles		2	2	2	2	2	2	2	2	**16**	22	150	352	2400
Little sized sweepers	2									**2**	22		44	44
Middle sized sweepers					6	6	5	5		**22**	22	150	484	3300
Large sized sweepers								3		**3**	22	150	66	450
													4075,1	15524,1

Figure 40. Power installed in 2030 to charge the fleet in AMIAT

The results show that in AMIAT:

- the total power used for the simultaneous charging all the vehicles in AC, needs to be at least 4075,1 kW;
- when DC charging is available the total DC/AC power used for the simultaneous charging of all the vehicles, needs to be at least 15524,1 kW

Knowing the number of electric vehicles associated with the working centers in the various years the results are declined for each of them.

The working centers linked with AMIAT, one of the society controlled by IREN Ambiente, are 9 and called:

- Germagnano;
- Gerbido;
- Zini;
- Ravina;
- Domodossola;
- Avigliana;
- Principe;
- Balangero;
- Rio.

In 2022 the installed power capacity for each working center is reported in table [8]:

Working centers	**Number of charging points**	**Technology provided**
Gerbido	15 + 4	220V (3kW) single phase + 380V 16A three-phase
Zini	38	220V (3kW) single phase + 380V 16A three-phase
Ravina	12	220V (3kW) single phase
Domodossola	10	220V (3kW) single phase
Avigliana	8	220V (3kW) single phase
Balangero	22	220V (3kW) single phase
Rio	40	220V (3kW) single phase

Table 8. Charging points in 2022

In figure [41], a graphic visualization of the energy needs in AC is represented while in figure [42] and [43] other two graphs are reported to give a better visualization of the energy needs in the working centers distributed on the north and south part of the city of Turin.

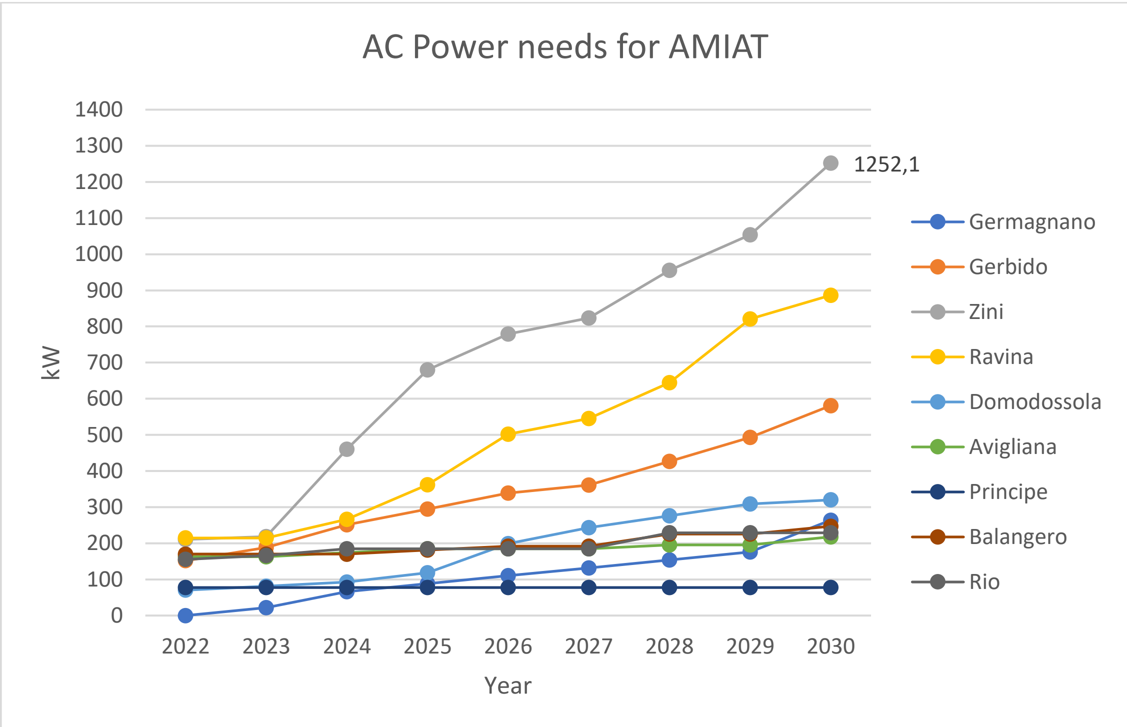

Figure 41. AC Power needs for AMIAT

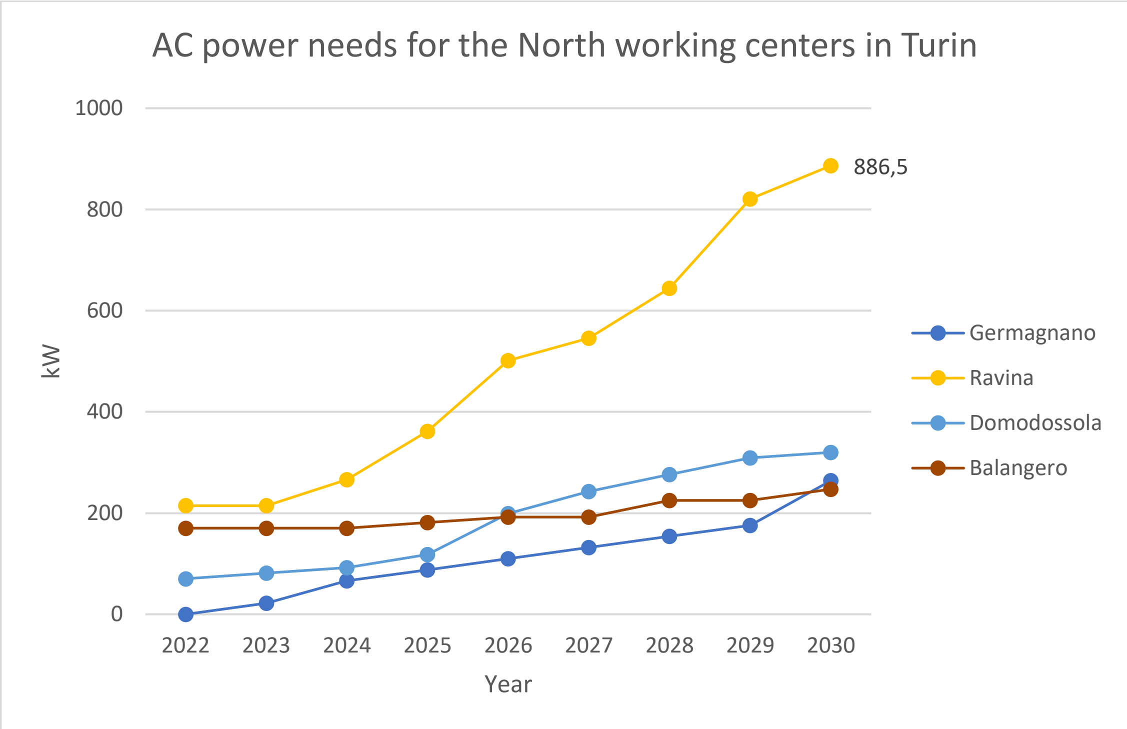

Figure 42. AC power needs for the North working centers in Turin

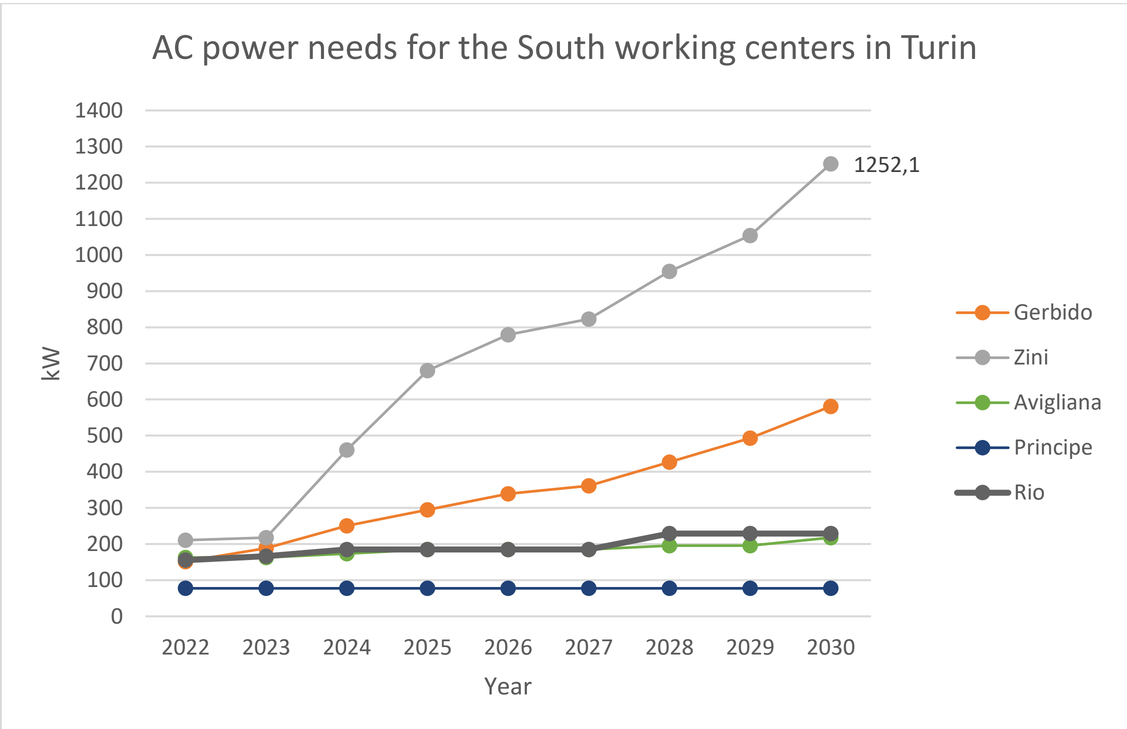

Figure 43. AC power needs for the South working centers in Turin

For the DC power needs the same analysis is performed for the different working centers distributed in the city of Turin. In figure [44] all the centers are reported while in figure [45] and [46] they are differentiated between North and South.

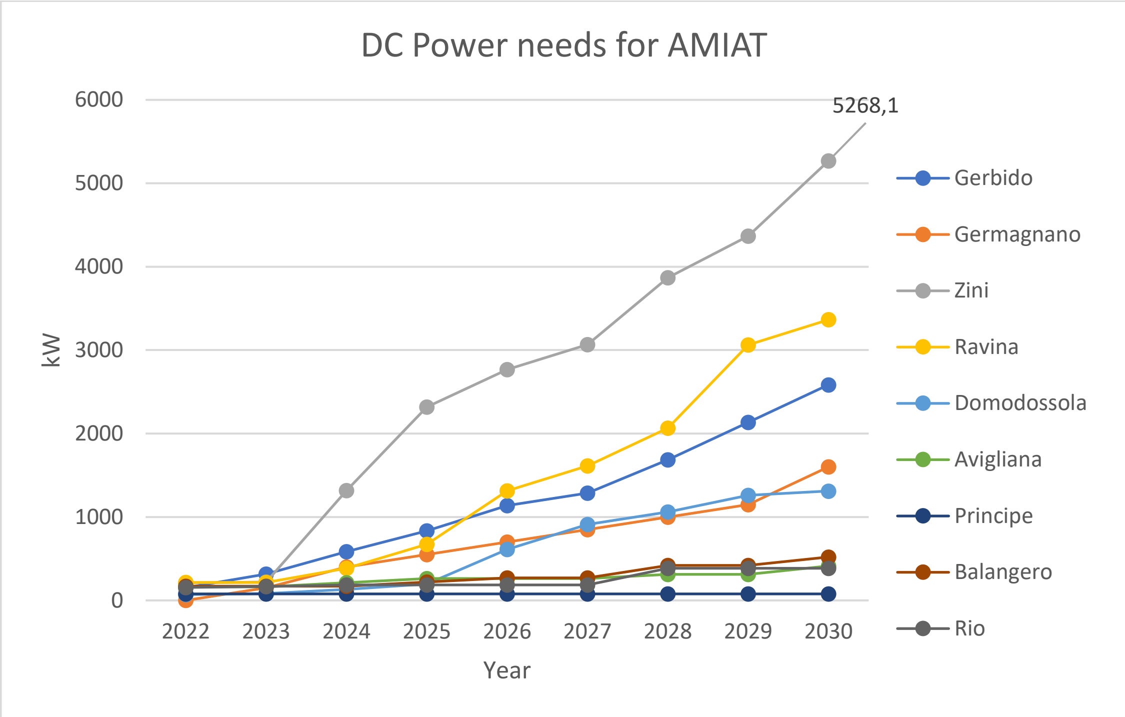

Figure 44. DC Power needs for AMIAT

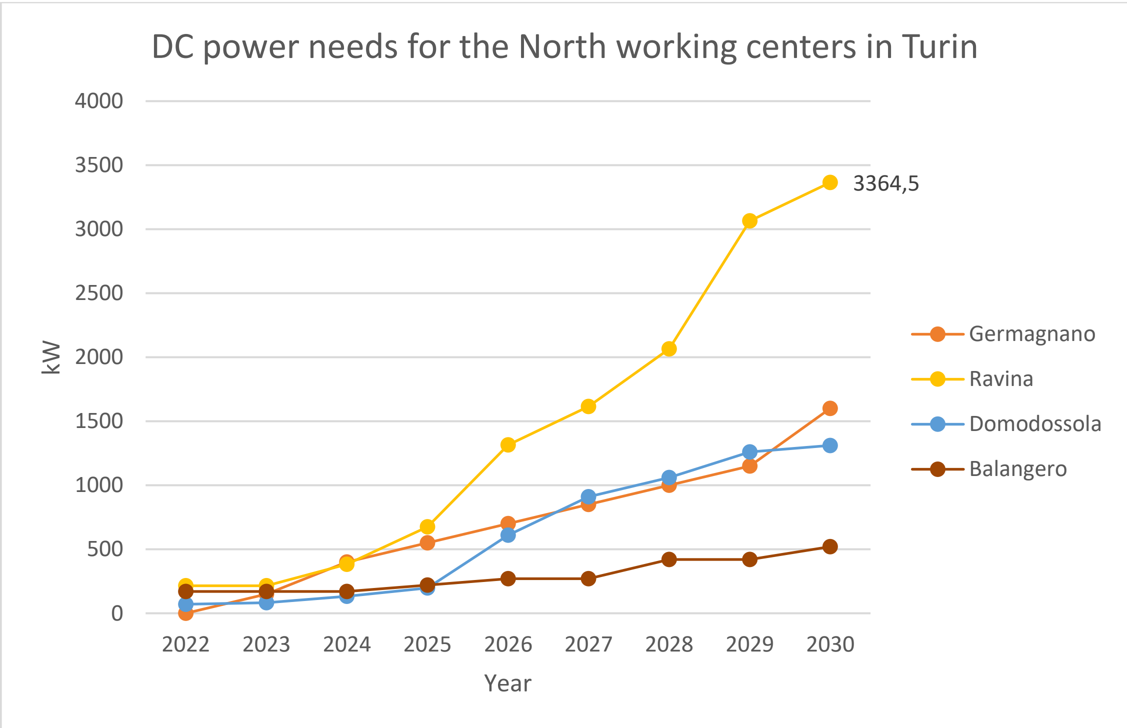

Figure 45. DC power needs for the North working centers in Turin

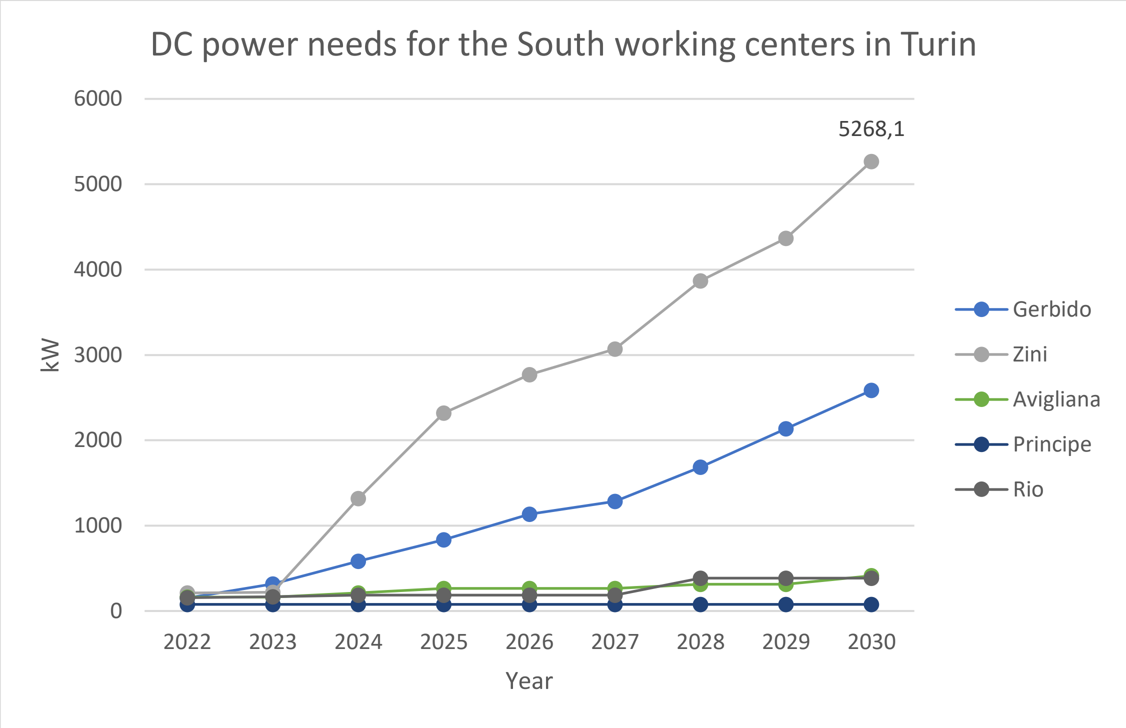

Figure 46. DC power needs for the South working centers in Turin

The analysis performed underlines that the working centers located in the South part of Turin are more energy-consuming. From the south of the city start alle the services are executed for the center part where, for matter of image other than lower environment impact, the business unit prefer to go with electric vehicles to complete the missions.

Graphs in figure [42],[43],[45],[46] are differentiated year by year to give a support to the department in charge of the installation of the charger points to divide the works in the years.

Knowing the total energy needs of AMIAT and the one that the working centers will require in 2030 a figure [47] demonstrating how impactful are the various locations on the total is reported:

Working centers	AC Power in 2030 [kW]	AC/DC power (DC where available) in 2030 [kW]	Percentage impact on the total (AC)	Percentage impact on the total (DC/AC)
Germagnano	264	1600	6,48%	10,31%
Gerbido	581	2585	14,26%	16,65%
Zini	1252,1	5268,1	30,73%	33,93%
Ravina	886,5	3364,5	21,75%	21,67%
Domodossola	320	1311	7,85%	8,44%
Avigliana	217,8	412,8	5,34%	2,66%
Principe	77,5	77,5	1,90%	0,50%
Balangero	247,2	520,2	6,07%	3,35%
Rio	229	385	5,62%	2,48%

Figure 47. Working centers power needs percentages

10. Fast charging, impact on lifetime of batteries and solutions

As reported in chapter [8] IREN Ambiente will acquire lot of electric vehicles in the following years changing her fleet from the one she has in 2022 to an entire green one in 2030.

In 2022, electric vehicles still facing problems like range anxiety and long charging times that in the context of urban hygiene can be too much impactful in terms of productive times.

Fast charging points and batteries capable to sustain fast charge can be the keys to solve part of the problem but charging at high rates has been shown to accelerate degradation, causing both the capacity and power capability of batteries to deteriorate. [14]

Battery degradation occurs because of calendar aging and cyclic aging related with battery chemistry, environmental conditions and use patters. [15]

There are two main forms of battery degradation: capacity fade and power fade.

Capacity fade is intended as a decrease of the amount of energy storable in a battery; it's measured in Amp-hours and is one of the parameters that most of constructor take in consideration when they consider a battery as at the end of her life when reaching the 80% of the initial capacity.

The rate of capacity loss is significantly dependent on charging/discharging conditions, including maximum voltage, depth of discharge, current and load profiles and temperature. [16]

Power fade is function of the internal impedance present in the battery, the amount of power that can be extracted will decrease over time because of an increase in the magnitude of the internal impedance.

As seen in chapter [9], the electric vehicles that will be acquired from the business unit can charge using alternating current (AC) or direct current (DC). AC charging mode is the slowest one of the two while DC charging mode is faster using a Combined Charging System (CCS) connector to provide power from the charging point to the vehicle.

In 2017, Porsche pioneered 350kW charging by unveiling two CCS charging posts rated to this power at the company's office in Berlin. [17]

EV heavy vehicles are usually equipped with battery pack operating at 400V but looking at the VOLVO FE 6X2 that will be adopted in IREN Ambiente it has a battery pack operating at 600V to reduce the high charging currents and to limit resistive heat generation.

Is important to underline that the charging is fast only in the range between the 0-80% of SOC but for safety limitations the amount of kW that can be immitted inside the battery decrease rapidly. The BMS controls the charging phase also limiting the maximum charging power. This system can protect the battery against deep charge/discharge and estimate the status of the battery in terms of SoC, state-of-health (SoH), state-of-function (SoF) and safety-of-safety (SoS) basing on outputs like temperature, voltage and current. [17]

In IREN Ambiente vehicles are not substituted before 8 years; in this amount of time the vehicles are amortized. For this purpose, is important to create a charging infrastructure where the DC charging system is limited to emergency cases.

An ideal battery would exhibit a long lifetime with constant proprieties for all her life making possible the charging in every environment at every temperature with maximum efficiency. Unfortunately, an ideal battery is not reproducible because of physics and thermal limitations.

The choice of the cathode and anode materials impacts on:

- nominal voltage;
- number of charging/discharging cycles;
- self-discharge rate related with involuntary reactions;
- specific energy;
- specific power;
- energy density;
- power density;
- optimal temperature operating range;
- cost.

Battery cell consists of two electrodes, a positive and a negative one, an electrolyte that reacts with both and a porous separator that physically divides the anode from the cathode to avoid possible short circuits.

The electrolyte is ionically conductive but prevents the flow of electrons between the two electrodes allowing them to flow only through the external circuit avoiding the possibility of self-discharge.

An example of discharge is reported in figure [48] for a battery equipped with an LMO (lithium manganese oxide) cathode and a graphite anode.

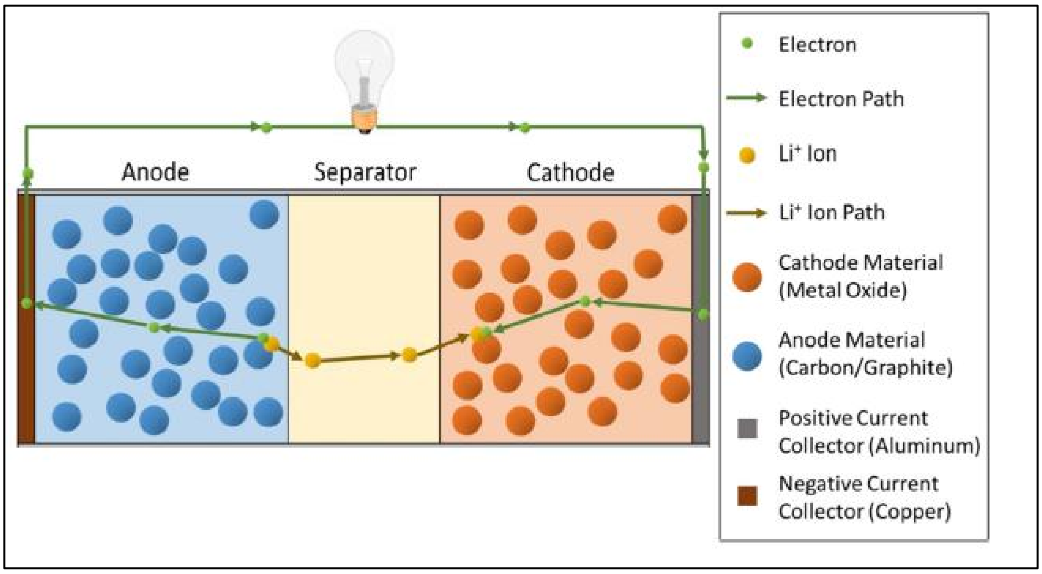

Figure 48. Example of discharge in a LMO battery [15]

During the discharge the negative electrode is oxidized by the electrolyte, this lets the electrons be able to move from the anode material through the negative current collector, the external circuit, and the positive current collector. While discharging at the cathode the metal oxide is reduced and the lithium ions flow through the separator from the anode to the cathode.

The opposite process is performed when an external voltage is applied to the battery while charging. The reactions for both the anode and cathode are reported:

$$Li_xC_6 \rightarrow 6C + xLi^+ + e^- \quad (48)$$

$$MO_z + yLi^+ + e^- \rightarrow Li_yMO_z \quad (49)$$

To represent ideal transport phenomena thin electrodes are considered but when they are sufficiently thick it becomes difficult to ensure the sufficient concentration of Li^+ at the interface between the electrolyte and the electrode to reduce to keep overpotential stable and reduce the chances for lithium plating. [18]

Lithium plating is a Faradaic side reaction in which the Li^+ ions in the electrolyte start to form lithium metal on the negative electrode instead of intercalating into it. [19] This phenomenon is one of the degradation factors involved in the decreasing of the lithium inventory.

The major degradation reasons in LIBs are loss of lithium inventory (LLI), related with the phenomenon in which the lithium cycled in every charge/discharge phase decrease, and loss of active material (LAM) where the lithium is consumed in side reactions decreasing the battery capacity because can’t intercalate anymore in the carbon structure of the anode.

LLI corresponds to the difference in lithium leaving the negative electrode and entering the positive electrode during the discharging phase [19] and can be quantified using the formulation (50):

$$\frac{dLLI}{dt} = S_{neg}\frac{dq_{neg}}{dt} - S_{pos}\frac{dq_{pos}}{dt} \quad (50)$$

Where:

- S_{neg} and S_{pos} are the scale factors;
- q are the electrode capacities.

While the capacity fade from LLI and LAM are not addictive and the overall degradation is function of the dominant mechanism, the power fade is the summation of the impact from both LLI and LAM. [18]

10.1 Anode and Cathode degradation factors.

Both Anode and Cathode degrade over time due to different mechanisms as reported before.

The major mechanisms for anode degradation are:

- SEI (solid electrolyte interphase) formation;
- metallic lithium plating;
- loss of active material.

SEI is formed during the first cycles in which lithium ions from the cathode along with organic compounds from the electrolyte solvent react with the graphite anode creating a thin film called SEI. The creation of this film irreversibly consumes lithium, decreasing the lithium inventory available for cycling and reducing battery capacity. [20]

The film is composed by organic salts, inorganic salts and trapped gas molecules consuming 10% of the initial capacity of the battery.

There is also a good role where SEI is involved and it protects the anode from further reacting with the solvent, is electrically insulating and has high selective permeability for lithium ions even if in real conditions anions, electrons, solvated cations, solvents and impurities can diffuse through the SEI. [18]

SEI layer formed during the first cycles can have a protective function, but during the aging of the battery it becomes unstable until it can penetrate the separator or block the pores of the electrode causing impedance rising, decreasing in the active surface area and safety issues.

The growth rate of the SEI is function of the temperature that is the major influencing factor.

The metallic lithium plating is a phenomenon in which when a battery is at high SoC, the anode has lot of lithium intercalated in its structure and the potential at the anode is low; if the potential is below 0V, lithium deposition becomes thermodynamically possible. [21]

Under certain charging conditions at the anode, the lithium metal can begin to deposit on the surface of the graphite blocking the accessible intercalations sites in the electrode. Usually, the lithium continues to deposit where deposits already exist, forming needle-like structures known as dendrites [22] that can cause short circuit. When the cycles are repeated the dendrites can also damage the cells from a mechanical point of view.

The lithium deposited on the electrode-separator interface has the potential to form a layer that can block the rest of the active material to transit. Metallic lithium is more reactive than graphite and can also promote side reactions that can result in SEI growth because of gas generation and electrolyte decomposition. [22]

Different factors influence lithium depositions:

- lithium diffusion rates within the anode;
- limited ion transport in the electrolyte leading to concentration gradients across the anode and salt depletion at the current collector. [21]

Usually, to prevent deposition, the anode is designed with a higher capacity of 10% (N/P ratio > 1.1) so the anode is never fully lithiated. [21]

Regarding cathode, the major mechanisms linked with degradation are SEI formation and loss of active material. The loss of active material can occur when transition metals (Ni, Mn, Co, Fe) in the cathode dissolve in the electrolyte [23] in a process so called transition metal dissolution (TMD) accelerated at high temperatures. Also the separator is vulnerable to mechanical damage from dendritic growth. Dendrites are generating from the deposition of lithium, TMD or copper dissolutions and can puncture the separator and lead to internal short circuits.

The SEI layer at the cathode is smaller than the anode one even if at high temperatures the one near the anode grows faster becoming more porous and unstable. [22]

Reactions between lithium and electrolyte also contributes to the formation of the SEI layer. During the charging and discharging and so the lithiation and delithiation the volume in the battery changes creating mechanical stress that could lead to cracking. These cracks can also be caused by gas generation related with high temperatures or from electrolyte decomposition. [15]

Not homogeneous lithiation can also induce structural phase distortions in the cathode structure in a phenomenon called Jahn-Teller distortion reducing the amount of active material. [19]

In thick anodes subjected to fast charging conditions the lithium salt may become depleted near the current collector affecting the utilization of the electrode and leading to an increase of the local current densities near the separator.

Also inactive battery components, like binder, current collectors and separator are subjecting to aging phenomena and degradations issues.

Binder materials due to high voltages and temperatures can decompose leading to LiF production processes that can increase the mechanical stress inside the battery while current collectors can corrode decreasing their conductivity leading to power fade during cycles. [15]

10.2 Degradation variables and improvements for a correct use of LIB batteries

Correct behaviors can be adopted to exploit all the useful life of the battery.

Knowing that lot of vehicles will be acquired from IREN ambiente, it will be important in next years to apply correct procedures to preserve the batteries.

The degradation mechanisms cited in chapter [10.1] depend on different parameters like:

- operating temperatures while charging or discharging;
- cycle depth;
- frequency and power of charging;
- change in state of charge;
- elevated voltage exposure. [24]

For heavy vehicles loss in capacity fade influences the number of PTO hours or kms that can be travelled while power fade impacts on the acceleration or the velocity in the movements of the equipment that will not be correctly powered anymore.

10.2.1 Thermal effects

Operating temperature in LIB batteries is an important parameter to take under control. Serrao et al. show that temperature above 25 °C accelerated battery aging. [25]

High temperature and high current rates are also related with the increase of side reactions that increase the loss of active material.

Heat, in Li-ion batteries, can be generated by reversible and irreversible processes. [22]

The formulations for the irreversible and entropic heat are reported down below in (51) and (52):

$$Q_{irr} = (V_{bat} - U)I \qquad (51)$$

$$Q_{rev} = I\frac{T\Delta S}{nF} \qquad (52)$$

Where:

- U is the open circuit potential;
- V_{bat} is the cell voltage;
- I is the current and is higher than 0 in charging mode;
- T is the absolute temperature;
- ΔS is the entropy change during the reactions;
- n the number of electrons involved in the reactions;
- F the faraday's constant.

The difference between the factors V_{bat} and U represents the total overpotential of a battery induced by processes such as the charge transfer reactions at the electrode/electrolyte interfaces.

Large part of the irreversible heat produced is represented by the Joule formulation in (53):

$$Q_{irr} = I^2R \qquad (53)$$

where R represents the cell resistance.

During the fast charge high currents are involved in the process and so more heat is generated following the quadratic relation. At high-C the rates the irreversible heat generation dominant while at low-C rates is the reversible heat generation to have the most impactful role.

The heat generated can dissipate in different ways following the geometry of the batteries. When situations of non-homogeneous current densities are present the heat is accumulated in particular regions and these inhomogeneities are aggravated for large format cells. [22]

The US National Renewable Energy Laboratory studied different aging models of Li-ion cells considering how temperature and cycles impact on the useful life of the batteries. [26]

The results demonstrate that the battery lifetime doubles when the average battery temperature during the storage and the cycling is reduced from 35°C to 20°C.

Low temperatures lead to slower diffusion, intercalation and kinetics with an increase in the possibility of lithium plating and dendritic growth. [22]

Most of the degradation processes are accelerated at high temperatures but lowering the operating temperature is not the solution. Low temperatures can decelerate the degradations mechanisms but slow down the diffusion of the active species changing the reaction chemistry.

10.2.2 SoC role in degradations processes

The SoC has a role in degradation processes for LIB batteries because of overcharge, over-discharge and high depth of discharge. The BMS has a central role to prevent all these phenomena controlling the temperature and the charge transfer.

Overcharge indeed can result in thermal runaway because external energy is being directly added into the battery [15] but is not a problem in EV vehicles because when they are plugged in recharging mode if they reach the 100% the BMS will absorb electricity to control the temperature of the battery pack. [27]

Reactions between lithium and the electrolyte contribute to the growth of the SEI layer but are also exothermic playing an important role in the thermal runaway. [22]

The lithium consumed by the SEI cannot be recovered and will cause an increment in the capacity fade.

On the other hand over discharge can be a problem if the battery is left for an extended period empty without being recharged. At this point the cells of the battery can experience capacity loss that can also affect the chemical stability. [15] Trippe et al. define 60% to 97% SoC as the correct window in which the battery is correctly preserved. [28]

C-rate is another parameter that affects the useful life of the battery because of higher charging and discharging currents and uneven distribution of current, temperature and material where the lithium ions intercalate.

High discharging rate where the heavy EV vehicle operates for lot of consecutive hours lead to short period of time for lithium transfer where they don't fully de-intercalated leading to capacity fade and lithium dendrite formation.

In figure [49] the comparison between low charging/discharging current and high discharging/charging current is reported showing lithium plating (1) and particle cracking (2).

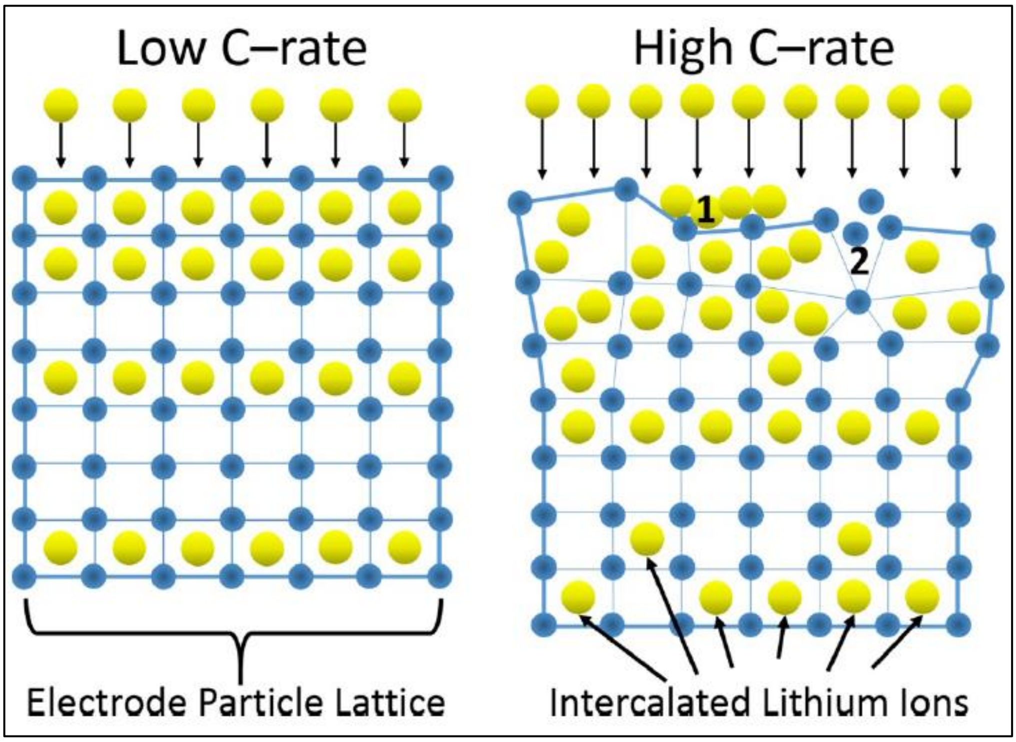

Figure 49. Lithium plating and particle cracking at different C-rate [15]

It's visible that low charging/discharging rate are preferred concerning high ones because of the slower ion diffusion rate in the charging time.

Regarding the degradation, the volume changes in the electrode material during the charging and discharging phases combined with the temperature variations induce stress that can generate cracks and delamination. [22]

Lithium plating occurs mainly during the fast charging because the electrostatic potential of the negative electrode approaches or falls below the one of the Li/Li^{+} reference electrode. [22]

If low temperatures are present during fast charging sessions, they also aggravate the not completed intercalation of the lithium.

10.3 Fast charging strategies

Different charging protocols are possible and can have huge impacts in terms of degradation in the battery pack and charging times.

The analyzed typologies are:

- standard protocols;
- multistage constant current;
- pulse charging protocols;
- boostcharging;
- variable current profiles.

Regarding the standard protocols the CC-CV is the most common one. [22] In this strategy a constant current charging phase is applied while the battery voltage increases until a cut-off value (CC phase), then a constant voltage phase is applied until the current value falls to near-zero.

CV phase is useful to allows the concentration gradients in the electrode particles to disperse to have high-capacity utilization. The CV phase is the most impacting in terms of charging time if compared with only CC charging strategy because the current decreases during the process.

Other strategies that achieve better charging times, increased efficiencies and/or improved capacity or power retention are reported in figure [50]. [22]

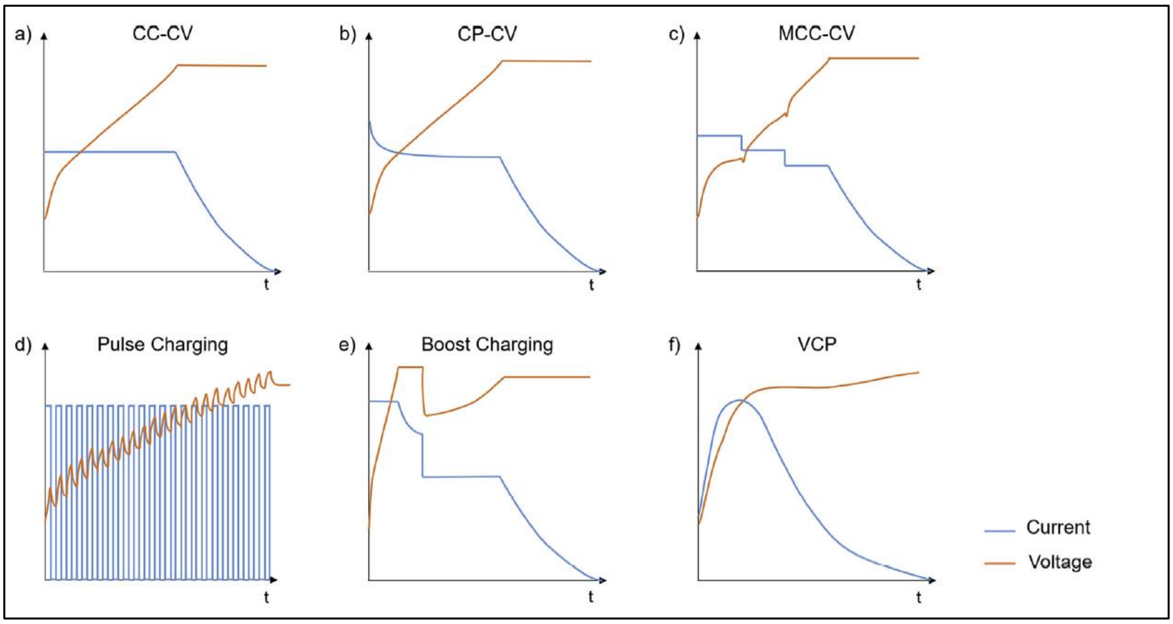

Figure 50. Charging strategies for fast charge

Multistage constant current protocols (MCC): Researchers have proposed that adjusting the current levels during the charging phases may limit cell degradation while reducing the charging time. [22]

The multistage constant current protocols allows to:

- reduce the heat generation;
- decrease lithium plating phenomenon;
- reduce the mechanical stresses when the diffusion of lithium is constrained.

As depicted in figure [50] different phases in which the current is constant are present and followed by phases where the voltage is constant too.

In the initial phases of the charging process higher current levels are possible due to the difficult possibility of the anode potential to became negative in the short term. [22]

Zhang [29] studied the impact of MCC charging protocol where the current levels increase in the last phases where the cell resistance is lower. [22] In this case faster capacity loss is observed compared to CC-CV and CP-CV (constant power, constant voltage) protocols.

The study underlines that CP-CV protocol is the best in terms of capacity retention over time when fast charged at 1C but if charging at 0.5C the less damaging protocol is the CC-CV.

Pulse charging protocols (PCC): In this case the charging current is periodically interrupted for short period or discharge pulses. [22]

The targets of these strategies are:

- reduce concentration polarization;
- reduce the risk of local anode potential to became negative;
- reduce mechanical stresses due to uneven insertion and extraction of lithium in the solid particles. [22]

For this protocol in the studies of Aryanfar et al. [30] and Li et al. [31] is demonstrated that:

- PCC protocols can inhibit dendrite propagation and growth;
- 1C PCC could reduce the charging time from 3.5h for a 1C CC-CV protocol to 1h thanks to the absence of the CV phases;
- better active material utilization is associated with PCC compared to CC-CV.

Abdel – Monem et al. [32] observed that comparing CC-CV, MCC and PCC protocols the rates of capacity fade were comparable until the 700th cycle but then the cells charged with the CC-CV protocols started to deteriorate faster while for MCC and PCC protocols the deterioration rate was similar.

Boostcharging: This protocol is characterized by high level of current at the beginning of the charging process, then a CC-CV phase part is present with moderate level of currents as reported in figure [50].

In this protocol higher currents or higher level of voltages are allowed if compared with CC-CV protocols.

Notten at al [33], tested different boostcharging protocol, lasting 5 minutes, on cylindrical and prismatic LCO cells.

For the cylindrical cells, comparing the tested performed by Notten at al. with 1C CC-CV protocol, the results showed that for boostcharging protocols the charging time was reduced by 30% with no noticeable acceleration in the capacity fade.

Regarding the prismatic cells a smaller reduction in the charging time is reported but with higher rates of capacity fade.

Variable current profiles: In this protocol different numbers of complex variable current profiles are proposed for the fast charging. Sikha et al. [34] studied a Varying current decay protocol (VCD) used to charge faster than CC-CV while being less impacting in terms of degradation rate. Better capacity utilization was possible in the early cycles but with higher capacity fade compared with CC-CV.

The Universal Voltage Protocol (UVP) was also proposed to reduce charging time and energy losses related to heating improving the overall charging efficiency. This protocol is derived from an optimization algorithm for a determined time and terminal voltage of different CC-CV charging curves. [22]

During the aging of the cells the current profile needs because of the increase in the resistance of the cells while the voltage profile doesn't need any correction. Maximum current is reached at low SOCs and then is gradually reduced due to limitation in the intercalated Lithium inside the graphite lattice.

The study [35] demonstrated that very high efficiency are obtained also for aged cells. The capacity of the LCO/NMC cells tested dropped to 80% after 370 cycles whit the UVP protocol in a similar charging time of the LCO/NMC cells charged at 2C but with CC-CV protocol.

10.4 Thermal management during charging processes

As seen in chapter [10.2.1] charging processes are related with heat generation; when fast charging processes are involved high heat generation rates are present and significant thermal gradients are generated.

Also low temperatures during charging processes can lead to detrimental effect on the cells.

Basing on which is the situation where the battery is operating, we can state that during charging processes high thermal conductivity is requested to cooling a hot battery pack while when operating at low temperature is important to retain the heat produced by the battery itself.

Regarding *cooling processes* the cooling media usually used in EV battery packs are air, liquid and phase change materials (PCMs).

Air cooling systems are cheap and simple but are not able to provide sufficient cooling rates because of low heat capacity and thermal conductivity.

Liquid cooling systems can be 3500 times more efficient than air [36] but high costs, complexity and possibility of failures are present. A possible option to cool down battery packs is represented by batteries immersed in cooling medium where good temperature homogenization can be achieved. [37]

The liquid NOVEC7000 (3M, USA) has demonstrated to be effective in cooling down battery packs achieving good surface temperature uniformity in an immersion system where a cylindrical Li-ion battery was involved. [37] Also at 20C the temperature of the battery module can be maintained at around 35°C using the same liquid. [38]

In PCM cooling systems the latent heat of phase change of the cooling medium is used to absorb the heat produced by the battery. [22] However, in cooling systems where PCMs are involved there are significant problems related with that at high ambient temperature the PCM could melt and release the heat previously absorbed and when the PCMs become liquid, due to the low thermal conductivity, it acts also like a barrier for the heat transfer processes.

During fast charging the temperature of the battery pack rise due to the high currents involved. The heat generated during charging processes is easier to dissipate when it comes from the regions near the outer surface compared with the center of a cell. The main reason is because the outer surface of the cells are typically in contact with the cooling media previously seen in this chapter.

In the recent years some hypotheses regarding external cooling technologies directly provided by the charging stations were proposed allowing reduction in weight for the EV vehicles.

Ford Global Technologies LLC have developed a system where the charging station can provide cooled air to the vehicle radiator during the fast charging where the temperature inside the battery pack rises due to the high currents. [39]

Liquid media is also an option able to cool down the battery pack during charging, indeed Tesla has patented a charging system where an automated charging connector can provide both cold and hot liquid to optimize the temperature range during the fast charging. [40]

About preheating in cold conditions, internal preheating methods are defined because of higher efficiency and better uniformity. [41]

Ji and Wang [42] thanks to a coupled electrochemical thermal model did a comparison between different ways to preheat the Li-ion cells in charging conditions:

- self-heating by discharging the battery;
- convective heating using a resistance where the current provided by a battery is flowing through and a fan;
- mutual pulse heating;
- AC heating.

Regarding self-heating by discharging the battery the method was discovered to be inefficient due to generation of power.

Mutual pulse heating allows to divide the battery pack in two groups of equal capacity, the charge is exchanged between the two groups in pulses using the resistance to produce heat; this strategy the efficiency is mainly limited by the DC/DC converter.

Compared with mutual pulse heating also AC heating seems to be promising to achieve higher heating speeds. [22]

Using 2.2Ah 18650 simulated cells using mutual pulse heating the cells where heated in 120s from -20°C to 20°C while for AC heating the same cells were heated in 80 s with a 10mV sinusoidal voltage wave with a 1000 Hz frequency.

10.5 Battery lifetime improvements

From the user behaviors point of view different precautions can be taken to exploit the maximum useful life of the Li-ion battery.

In EV vehicles the depth of discharge (DoD) is linked with the driving speed and acceleration and so to the battery discharging current.

Stroe et al. in their study [43] developed a daily aging profile based on WLTC where 22h of cycling and 2h of stand-by were done assessing the aging of NCM-based battery cells. The location of the analysis was Seville, Spain and the temperature changed monthly according with the climate conditions.

After eleven months of tests and aging the 2 cells tested lost 10% of their initial capacity as reported in figure [51].

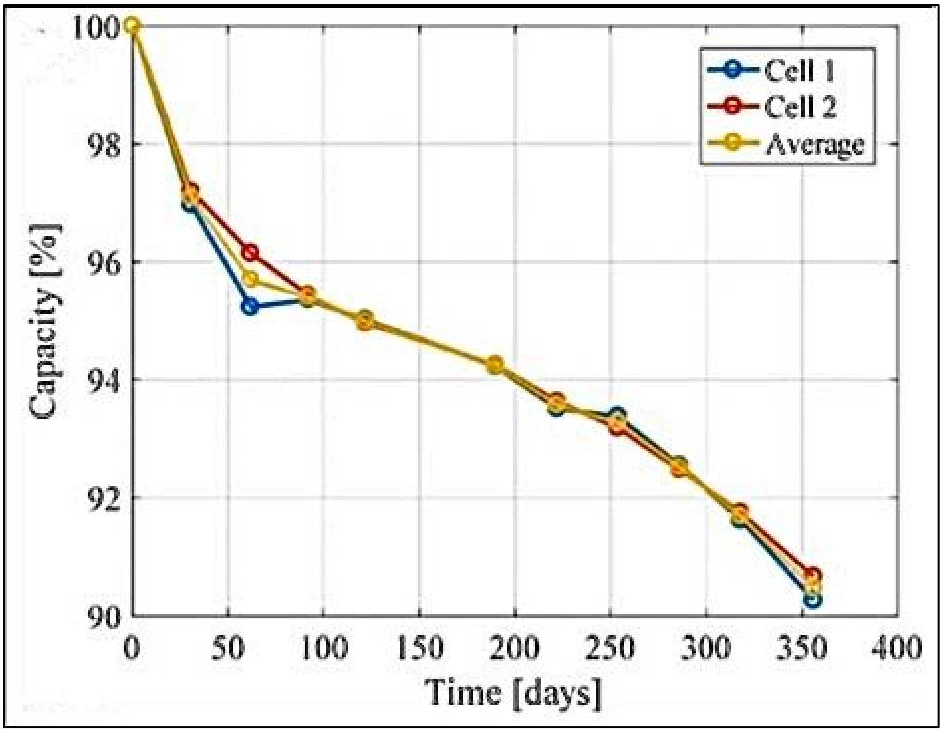

Figure 51. Capacity fade during aging in eleven months [44]

The relation between environmental temperature and capacity fade is reported in figure [52].

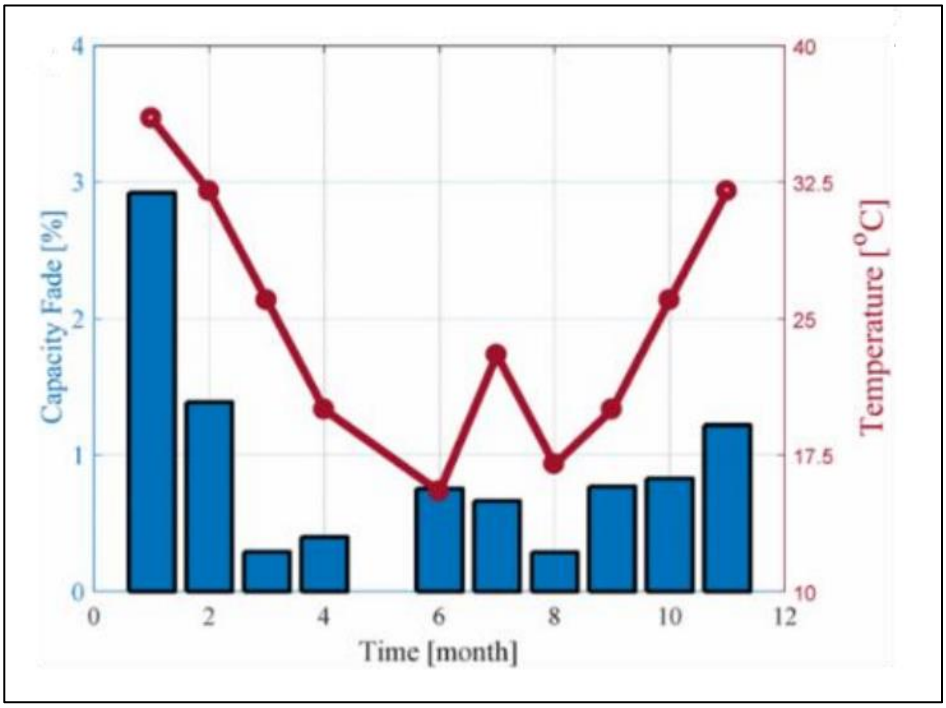

Figure 52. Capacity fade and temperature relation [44]

As noticeable, the worst cycling temperature was 36°C where the 3% of capacity fade occurred. During the aging processes also the resistance increases due to an increment in the dimension of the SEI layer that also causes an irreversible capacity loss. [44]

As previously seen in chapter [10] elevated temperatures accelerate degradation in almost every component of LIBs and the impact is even greatest when combined with high voltages. [15]

Elevated temperatures degrade the battery both during charging and operation creating also possible safety risks due to gas generations. [15]

Minimizing the exposure to high temperatures in storage and use and to low temperature during charging are key factors to preserve the battery during aging.

Minimizing also the time spent at 100% and 0% SoC is an important recommendation. The battery pack should be partially charged to create less mechanical stress on the anode due to the complete lithiation. If 30% of the battery's capacity is needed, is better for the battery to operate in the range between 80%-50% instead of 100%-70%. [45]

Also low SoC create stresses on the battery; the BMS usually stops the vehicle before it reaches 0% of battery capacity to avoid over discharge that can create permanent damage on the cells. When leaving an EV vehicle disconnected from the electrical grid for a long period, it can be a good habit to make sure that the vehicle is charged for a certain percentage knowing that a certain discharging rate even out of operations is present.

Regarding the fast charging most of constructors prescribed a certain number of cycles that the batteries can sustain. Repeated use of fast chargers can degrade the batteries quicker than expected if compared to standard charging in AC.

11. Conclusions

The maintenance engineering has a key role for IREN Ambiente and its functionality is strictly related with the needs of the services department to have the vehicles correctly operating to complete the disposal orders assigned by the cities where the business unit operates.

Thanks to the use of UNI EN 13306:2018, UNI EN 11063:2017, UNI EN 15341:2019 and UNI 11440:2022 the economic and technical KPIs are identified and calculated given the data mined and extracted from SAP PM and SAP WASTE for sweepers vehicles.

The KPIs computed highlighted a situation in which the corrective maintenance processes account for most of the maintenance operations with 90,7% of them and a cost of 84,4% compared with the total of the maintenance processes performed.

To enhance the economic KPIs ample room of improvement is present acting directly reducing the cost of spare parts signing contracts whit the suppliers that sell the item to IREN Ambiente. Lowering down the amount of corrective maintenance orders is also an option able to lower down the total costs for the operations entrusted to external workshops that usually have higher labor costs compared with the one of the internal workshops.

Increasing the number of preventive maintenance processes allows also to decrease the down-time of the vehicles thanks to a better scheduling of the interventions inside the workshops ensuring to the services department the correct number of vehicles to complete the missions.

Regarding technical KPIs the target in the next years will be to improve the OEE, according to the technical limits present, and increase also the MTBF acting on the mean time to solve a failure.

The improvements reported in chapter [7] have the target to:

- increase the overall efficiency in the working schedule thanks to the organization of different operations levels that can be assigned to the maintainers following their levels creating a pyramidal hierarchical structure able to improve the know-how of the maintainers and their ability to work in group;
- create a structure able to process the predictive maintenance processes thanks to the implementation of a system composed by two phases, one for the estimation of the coded operations and their frequencies and one for the correction of the timing cycle, to lower down the number of failures and corrective maintenance processes;
- give a support to the workshops to better understand the priorities of the vehicles to be repaired using an user informatic interface where the service department needs are reported.

Knowing that IREN Ambiente will have an entire green fleet in 2030 the maintenance processes need to be adapted to respect the security regulations and the actual infrastructure needs to change following the number of electric vehicles that will be acquired by the business unit.

Until 2030 the electric vehicles already owned in 2022 will be replaced in the years and other will be bought incrementing the total amount of electric vehicles in the IREN Ambiente’s fleet.

The analysis performed in chapter [9] concluded that the installed power capacity in 2030 will be 4075,1 kW for vehicles charging in AC and 15524,1 kW for vehicles charging in AC and DC where possible.

In the different working centers, the tendencies reported for the installation of power capacity are similar with different values following the vehicles assigned. In particular Zini and Ravina will need in the following years the majority of investments due to the assignment of large part of middle-sized sweepers.

Fast charging will have a key role in the management of those vehicles that operate within two work shifts. The use of 50kW (or more) DC charging point needs to be limited and also the itineraries of the various missions need to be calculated and evaluated according with the storage capacities of the storages.

Lithium plating, dendrites formations and SEI layers are promoted by fast charging and wrong management of the Li-ion batteries. As described in chapter [10] the limitation of using the EV vehicles at 100% of SoC added to niceties like avoiding over discharge, low environmental temperature while charging and high DoD will impact on the correct management of the battery pack resulting in vehicles that can last for more time.

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