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LIFECYCLE MONITORING FOR THE AUTOMOTIVE ECO-SUSTAINABILITY

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ABSTRACT
The growth sustainability requires dramatic changes to lower the natural resources consumption and the surroundings pollution, by recovery/remediation processes. The EU policy aims at the extended producers/suppliers responsibility, with effective charges on the products allowed to be put on the market, used and called-back, in view of the properly small impact and transparent lifecycle acknowledgement. This leads to «extensions» in designing the new offers with integrated monitoring and service functions.

The design for the lifecycle eco-effectiveness is accomplishment, better qualifying the far-seeing companies according to the EU eco-policy. The idea is to reach the duty visibility, by the extended plug-and-play concept, based on series of integrated design options, assigning the structural and functional modules, for the operation monitoring, the reliability assessment and the impact appraisal. This instrumental setting includes intangible information/communication aids, to confer ambient intelligence abilities. This way, the on-process visibility is assured, and exploited for on-duty servicing and end-of-life processing.

The example case chosen deals with the critical situation of the parts manufactured in plastics, which are deemed to represent most relevant portion in the cars to come. The following recovery options are possible:

- the reuse of the reconditioned items, according to suitably assessed life-extension opportunities;
- the recycling of the warn-out components, with the regeneration and reusing of the materials;
- the thermal recovery of residual stuffs, within careful handling and pollution-safe warnings ;
- the reduction to registered ASR, automobile shredding residue, within the EU directives limits.

The on-board information system includes, as innovative feature, the resort to identifying tags or labels, to be read and written through wireless links. The technology exploits cheap and compact supports, allowing the labelling of the component, from production, to lifecycle, with an identifying code. The RFID, Radio Frequency Identification Device, is privileged, as ideal means for the component traceability and the history, use modes/styles and cumulated issues storing.

ACRONYMS
ASR, Automobile Shredding Residue.
ELV, End-of-Life Vehicle.
MEMS, Micro Electro-Mechanical System.
PLM-RL, Product Lifecycle Manager for Reverse Logistics.
PLM-SE, Product Lifecycle Manager for Service Engineering.
RFID, Radio Frequency Identification Device.
SSD, Solid-State Disc.
WEEE, Waste Electrical/Electronic Equipment.

1. INTRODUCTION
The growth sustainability requires dramatic changes to lower the natural resources consumption and to avoid the surroundings pollution, through recovery/remediation processes. The EU policy aims at the extended producers/suppliers responsibility, with effective charges on the products allowed to put on the market, used and called-back, in view of the properly small impact and transparent lifecycle acknowledgement. This leads to «extensions» in designing the new offers with integrated monitoring and service functions. The EU policy, thereafter, issued a series of directives, with mainly, two scopes [1-5]:

- to establish stringent conformance-to-use requirement for monitored eco-impact, thus, implicitly, to foster voluntary agreements towards the product-service market;

▪ to enact compulsory recovery target at artefact dismissal, with economic instruments turned on the free take-back requests, with the explicit suppliers' involvement.

The end-of-life vehicle, ELV, and the waste electrical/electronic equipment, WEEE, are known cases, where mandatory eco-rules already bind the manufacturers/dealers, asking demanding targets. More in general, the design for the lifecycle eco-effectiveness is accomplishment, which better qualifies the far-seeing companies. According to the EU environmental policy, the idea is to reach the duty visibility, by the extended plug-and-play concept, based on series of integrated design options, starting by incorporating structural and functional modules for the operation monitoring, reliability assessment and impact measurement. The instrumental fit-out includes intangible information/communication aids, [6], to confer ambient intelligence abilities. This way, the on-process visibility is assured and exploited for on-duty servicing and end-of-life duties. The information can be used in various ways to enhance integrated eco-design from earliest conceptualisation.

The paper primarily addresses the ELV case, already covered by the EU environmental policy. The lifecycle assessment visibility is believed to be preliminary step, allowing the subsequent decision-frame, to select the most effective recovery (reuse-recycle) targets and the re-design up-grading. For explanatory purposes, the chosen example case, [7], deals with the crucial situation of plastics manufactured parts, which are deemed to represent most relevant portion in the cars to come. The plastic is used also for structural components, with critical strength and reliability requirements, so that recycled stuffs are suited. For example purpose, the brake pedals are addressed. The following recovery options are devised:

- the reuse of the reconditioned items, once verified and warranted their safe operation reliability;
- the recycling of the warn-out components, with certification of the secondary-material quality;
- the thermal recovery of singled-out stuffs, assuring the requested emission eco-compatibility;
- the reduction to registered ASR, only, whether the previous options cannot be accomplished.

The on-board information system includes, as innovative feature, the resort to identifying tags or labels, to be read and written through wireless links. The technology exploits cheap and compact supports, allowing the marking of the component, from production, to lifecycle, with an identifying code, assigned according to the ISO 155693 standard, and its specification, adding or removing the appropriate data. With regards to cost, in-progress technology evolution and extended versatility, the resort to the RFID, radio frequency identification devices, is privileged, as ideal means for the component traceability, with record of the life history, operation modes/styles and cumulated issues.

Actually, one needs never to forget that, according to scope economy, the road map has to aim at optimising the overall resource usage, possibly, to achieve the (mainly) neutral set-up in tangibles decay. The practice of design-for-restoring, -for-maintenance, -for-dismantle, -for-recycle, etc. is forward-path duty, to improve the conservativeness. This leads to the some shrewd features, such as: self-tuning ability, when disturbances off-set running requirement; pro-active maintenance with monitored figures; schemes for tangibles call-back or final withdrawal, based on actually assessed work-conditions; and the likes. In short, the lifecycle visibility is inherent commitment, and the enterprise responsibility has to cover the all duty-cycle. When the concern on the backward path opportunities increases, [8], new business demands appear, as generic choices:

- planning for quality protection of the used items, easy disassembly, material reuse, etc.;
- designing for long-life availability, rare maintenance, low energy consumption, etc.;
- preferring self-tuned rigs, high yield applications, re-used packaging, improved logistics, etc.;
- setting optimal on-duty effectiveness, pro-active up-keeping, etc. product-service supply;
- choosing high throughput, material saving, energy recovery, etc. operation processes;
- making extensive use of recycled, less energy-intensive, renewable, etc., materials;

either, [8], these betterment choices are introduced as specific recovery options, to address:

▪ re-conditioning, say, to back establish the original conformance to specification, by combined industrial processes applied at the life end of the artefacts; re-conditioning is limited, if the re-setting is partial;

▪ re-manufacturing, say, to recover parts and material matching original properties, by combined industrial processes applied to dismissed artefacts, and to candidate them to new duty-cycles; the issue is limited, if the processed parts do not recover the original characteristics.

The design for the backward path eco-effectiveness is far from self-consistent, as it needs to incorporate the knowledge of the design for the forward path eco-effectiveness. Then, recovery is interpreted to combine many side-effects, notably, the reuse (re-conditioning, re-manufacturing, etc.) specific opportunities, and these are investigated to improve the overall resource productivity, using the forward path life-extension, as standard recovery technology. The productivity increment (by respect to the use-and-dump of the affluent society) is deemed to be relevant, if promoted by the knowledge entrepreneurship [8], where the information flow dominates, as compared with the transformation of tangibles.

On these facts, the paper summarises the main demands arising from the eco-sustainability challenge, having proper focus on the complexity that the new requests will affect the trends of the manufacturing business. It is, thereafter, addressed a case investigation, assuring twofold outcome: it permits to deal with factual issues, directly addressing the empirical knowledge framework and the related experimental set-up, necessary when the product lifecycle is becoming the winning attribute of the current supply chains; it helps understanding the theoretical background of the (future) knowledge-driven entrepreneurship, which has to develop to grant the growth sustainability, within the ecologic constraints that cannot be anymore delayed.

2. THE SUSTAINABILITY CHALLENGE

The lifecycle visibility is preliminary step, allowing the ensuing decision-frame, to select the most effective recovery (reuse, recycle) policy in front of the finally privileged EU position. The example case, hereafter chosen deals, with the critical situation, in the automotive areas, of the plastic components, which are used, also, for structural components, with critical strength and reliability requirements, so that the recycled stuffs could not be allowed. Indeed, the EU policy foreshadows the following tracks:

- the reuse of the reconditioned item, once verified and warranted the safe operation reliability;
- the recycling of the warn-out components, with certification of the secondary-material quality;
- the thermal recovery of singled-out stuffs, assuring the requested emission eco-compatibility;
- the reduction to registered ASR, only, whether the previous options cannot be accomplished.

The first, only, belongs to the forward supply chain, delaying the item's life end. It deals with the product-service delivery, distinguishing the embedded, from the ambient intelligence. The former assures the local knowledge build-up; the latter, its communication management by outer outfits. The recovery by condition monitoring up-keeping aims, [8], [9] at:

- proactive regeneration, if zero-defect schedules establish on the strategic horizons, due to embedded ability;
- reactive restoration, if the detected anomalies are removed at stops scheduled on the execution horizons.

However, the embedded diagnostics is of no help, unless suitable regeneration outfits are included since the design/manufacture steps, with the additional cost and sophistication. The proactive maintenance complexity and price advise against its fully autonomous solutions, and the efficient alternative is reactive up-keeping, with remote diagnostics and restoring planning. The concept behind the alternative is to have information when you need it in one place, and to plan the recovery service provisions by smart and lean efficiency. The knowledge-base (system assumptions, reasoning abilities, etc.) can have remote location, where the process data are transmitted and processed, for inferring diagnoses and feed-forward plans. This facilitates managing the decisions for maintenance, trims the expenses and helps lowering the wastes. Remote diagnostics is, in fact, consistent with reactive restoring, after provisioning the remediation equipment, but, also, with basic proactive actions, if the nominal state is brought back to the original conditions by the embedded functional redundancy, so that the regeneration is enabled by 'switching-and-play' built-in options. The diagnostics and recovery are operations with different implementations, whether the instrumental enablers are distributed or centralised. The big difference between the hardware, either software, instruments is that multiplication of the former means, each time, their duplication; while, for the latter, remote measurement and networking assures the efficient sharing. The condition monitoring duties are, [8], [10]:

- to detect and identify the abnormal situations, defined in terms of operation features or drifts;
- to acknowledge the fault situation, defective components, level of degradation, type of failure, etc.;
- to troubleshoot, assessing the restoring policy and actual replacing/maintenance interventions.

The development of the central diagnostic knowledge is time/cost consuming and demands big efforts. Its generalisation in several businesses is difficult, even if the scenarios belong to one company and the tool, to be used in similar technical contexts, is standard.

The design for the backward path eco-effectiveness should be at more advanced level, at least, in the case of the durables, ELV and WEEE regulated by «mandatory targets». This is only partially true. The rules apply to the reverse logistics end-of-life products; but the backward flow deals with the up-grading of old items or the replacement of damaged pieces, making factually overlapping the forward and backward paths. Besides, focusing on the parts and materials processing after the handed commodity (partial or total) dismissal, the information contents are not neutral, because the designers have considerable data on the product lifecycle technicalities, but, up now, very little information on the efficacy that might be reached with the lifecycle data; thus, two restricting patterns establish to operate throughout, [8], [11]:

- the feedback of forward path features, to recognise the appropriate design-for-X specifications, to be added in the product lifecycle manager/service engineering, PLM-SE, database;
- the forecast of backward path features, to include suitable design-for-recycling specifications, to be included in the product lifecycle manager/reverse logistics, PLM-RL, database;
- the former, requesting the designer responsiveness with further data, obtained by on-process monitoring; the latter, possibly, covering the tangibles flows after the artefact dismissal, when the data collection is, most of times, done on the processing of mixtures of items, only in-the-average referred to the original supply chain.

On these premises, the sustainability challenge demands the appropriate visibility of the lifecycle data, which need to be fully monitored and vaulted.

Aiming at clear and fully verifiable issues, focus is put on a specific component, the brake pedal, in order to assess its lifecycle, recovery included, ecological and economical performance. Vital relevance bears the on-duty state (cumulated stress) in view of the item's cumulated damage. The data heavily affect the economical return at withdrawal, for re-manufacturing, and, thus, for the part reuse or material recycling. The wide resort to safety active devices, such as the ABS brake assistant that inhibits the wheels blocking, allows the driver to apply even very high forces, without risks on the vehicle stability.

The present project, in keeping with the outlined request of lifecycle visibility, shall develop the linked data acquisition and vaulting fixtures. The experimental set-up makes use to identifying tags, to be written and read through wireless links. The technology exploits cheap and compact supports, allowing the labelling of the component, from production, to lifecycle, with an identifying code, univocally assigned according to the ISO 155693 standard, and its specification, adding or removing the appropriate features. In terms of cost, the in-progress technology evolution and the extended versatility, the resort to Radio Frequency Identification Device, RFID, is privileged, as ideal means for the component traceability and the history, use modes/styles and cumulated issues storing. At the moment, the amount of inscribed data in RFID is quite small; to remove the limitation, a remote on-board intelligent module ought to be added, with the capability:

- to acquire the measurements from the on-the-field sensors;
- to process the detected data, reckoning the sub-set of characterising signatures, specifying the operation modes, the severity indices, etc., writing the pertinent knowledge on the label;
- to read/write the information, for subsequent up-dating or completion.

On the remote module, a virtual instrument is programmed, having in charge to compute and to store two different kinds of knowledge:

▪ the short-term data, providing more details on the on-duty conditions and on the operation modes of the components, which, due to their redundancy, need to be vaulted into external archives and saved at regular time intervals;

▪ the long-term data, supplying synthetic features of the component overall life, which are written on the RFID.

Looking, for example purpose, to the car braking pedal, the on-process information frame could refer to observation schemes monitoring:

- the number of pedal actuations, given by a counter driven by micro-switches;
- the averaged duration of pedal actuation, obtained combining the micro-switches and timers;
- the variance of the pedal actuation averaged duration, computed in parallel with the above data;
- the actuation law, provided by MEMS accelerometers and subsequent processing of the data;
- more specific operation «styles», such as high/weak strokes, prolonged/iterated features, etc., reckoned by detecting and coding the pertinent signatures corresponding to the singled out drivers' habits.

The module can be integrated within the car computer: the short-term data are collected and checked during the standard maintenance and conformance assessment operations. This way, a fully transparent information system is created, assuring process visibility to the different stakeholders: car-makers, users, car-repairing shops, car-breakers and certifying/controlling entities.

The healing/restoration features are established with due regard to the specific product-service delivery. One has to distinguish the embedded, from the ambient intelligence. The former assures the knowledge build-up; the latter, its communication management by outer outfits. The knowledge-base, the system hypotheses, the reasoning abilities, etc. can have a remote location, where the on-process data are transmitted and processed, for inferring diagnoses and feed-forward plans. Such aids facilitate managing the decisions for maintenance. Remote diagnostics is, in fact, consistent with reactive restoring, after provisioning the remediation aids, but, also, with elemental proactive actions, if the nominal state is brought back to original conditions by the item functional redundancy, so that regeneration is enabled by 'switching-and-play' built-in choices. The option is, here, above all relevant for the communication/processing devices (not the component itself), and, for better friendliness, for the ambient intelligence support; it is properly assessed by the virtual instrumentation approach.

The ambient intelligence authorises easy interaction, with plain language or any other means a non-computer specialist uses to communicate. Without entering here into details, the functionalities of a remote diagnostics tools are standard reference, [6], and, typically, split into six blocks:

- the common knowledge-base stores all the product-process-enterprise-environment information, to be the up-dated reference of the integrated design process, in view of the product lifecycle management PLM, the service engineering SE (and/or the reverse logistics RL) frames;
- the set-up module is a data-base manager, with graphic interface, to enable the user to follow and understand the process under observation, with related diagnostics frame, and to make the best use of it, by supporting the definition, modification, storing, deletion, etc., of the common knowledge-base elements;
- the information processing module maps the input (supplied by distributed sensors) into the common knowledge-base elements, according to the idea that the ambient data can be expressed into any format and the detection/transmission is operated automatically, without explicit peripheral concern;
- the diagnostic engine provides interactive problem-solving support to the users with resort to heuristic rules, case-driven reasoning, etc. and connects, e.g., by means of the common object request broker architecture, to the common knowledge-base, to make decisions and to friendly acknowledge diagnostics signatures, by functionalities fully hidden from the system user;
- the product support module is the core of the remote diagnostics service, with the products data (operation, maintenance, disassembly, etc.), etc., to accomplish the process instantiation of extended artefact delivery, assuring

that the operation unit sees the virtual image of real network, supported by the structured database, this allowing the protected access to the certification/supervision duties;
- the knowledge analysis module allows the data restitution and reporting, by spot data (database query, etc.), statistical outcomes (Pareto charts, etc.), knowledge analyses (on-duty reports, etc.), etc., with connection to the common knowledge-base, through the product support module.

The sketched case situation shows how specialised companies, with domain proprietary technologies, could turn into effective product-service, supplying lifecycle assistance, provided that information/communication aids specialise into PLM-SE tools.

3. THE INSTRUMENTAL SET-UP

In the section, the instrumental architecture, Fig. 1, is outlined, as explanatory example applied to the chosen car component. Three main parts distinguish:

- the local tags, RFID, whose duty is the item identification and current history signatures;
- the interface, sensors, transducers and transmitters, charged to provide the monitored data;
- the on-board processor, for the signals acquisition and conditioning and the data storing.

Miniature, screening, current-proofing and low-power consumption figures are basic requirements.

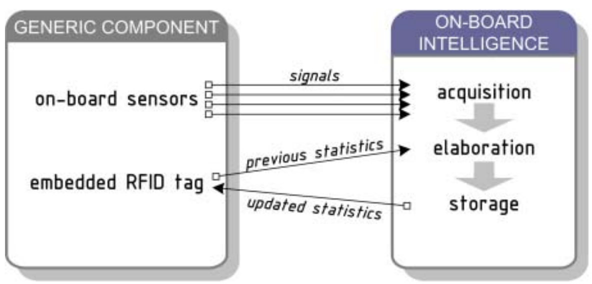

Figure 1. The on-board architecture.

The local intelligence provides the means to acknowledge the component history, the users' driving style, the cumulated damage and any other relevant information, all along the on-process operation. Moreover, the link to the central diagnostic and decision-keeping unit assures the suited related actions, with the full traceability of the lifecycle properties.

The virtual instrumentation set-up permits checking the basic tasks allotted to the on-board intelligence:

- to acquire the signals from the on-the-field sensors;
- to extract the signatures and convert the information into physical units;
- to store the data on the on-board solid-state disc, SSD, capable of vaulting up to a few gigabytes;
- to perform the data-processing (diagnostic features, pertinent statistics, etc.) for the local intelligence;
- to write-back the synthetic lifecycle figures (statistics, etc.) on the item RFID tag.

Additionally, in terms of the PLM-SE accomplishments, the further typical tasks are:

- to connect the on-board intelligence, with the servicing operator terminal;
- to upload all the data of the on-board SSD, to servicing (manufacturer) terminals;
- to share the car-embedded data and to compare the in-progress whole averaged figures.

Moreover, with the lifecycle car-maker responsibility, the PLM-RL auxiliary tasks are:

- to compress the data on the on-board SSD, whether the storage space is shrinking;
- to clear the data of full SSD, replacing them by "equivalent" lifecycle indicators;
- to collect the lifecycle data, in view of their back-use for re-design, re-engineering, etc. duties.

With focus on the example component chosen for explanatory purposes, the instrumentation gives the details related to the brake pedal, Fig. 2.

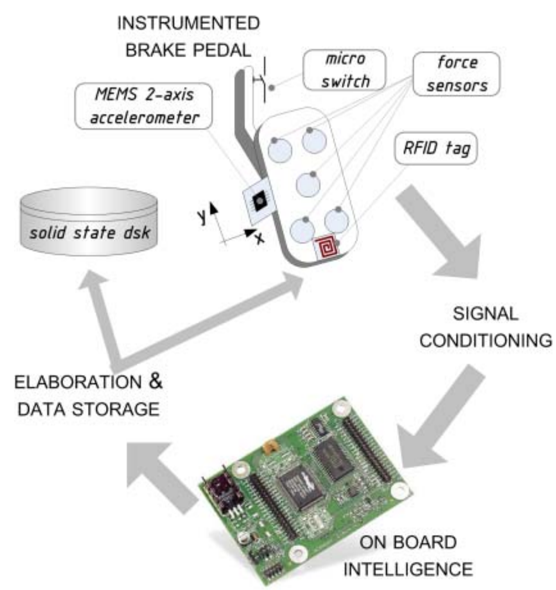

Figure 2. The pedal intelligence set-up.

The quantities to be monitored, according to the previously recalled details, are properly obtained with resort to the following devices:

- on-board clock, to get the acquisition timestamp and the actuation time-length, with resolution provided by a 22.12 MHz resonator, doubled to 44.24 MHz;
- micro-switch, to detect the actuation history, with resort to the (existing) braking back-light switch;
- two-axis MEMS accelerometer, to measure the pedal acceleration/deceleration during car-breaking, having 3.9 mV/ms^{-2}, with 0.2% deviation from linearity and 80 dB dynamic range, so that the maximal detectable acceleration is 490.5 m/s^2;
- piezo-resistive three thin-film force sensor, to assess the applied pushing force, with 45 N maximum load, having 5 s

response time, 5% deviation from linearity and less than 4.5% limit hysteresis once applied the 80% load.

The on-board intelligence module is Rabbit BL2600, with the following properties: - 44.2 MHz core micro-processor, with 512 kB Flash and 512 kB SRAM; - 5 serial ports (RS-232, RS-485); - one 10/100 Base-T port; - 128 MB of CompactFlash storage memory; - 8 analogue input channels, with 11-bit resolution, and range from ±1 V to ±10 V or 4-20 mA at a scan rate of 12 kHz; - 4 analogue output channels with 12-bit resolution, output range 0-10 V or ±10 V or 4-20 mA at up-date rate of 12 kHz; - 16 digital input at ±36 V, 200 mA; - 4 digital output at ±40 V, 2 A.

The experimental set-up, prepared for the laboratory investigations on the car-brake pedal is, by now, only stitched on the surface (not incorporated in the material, as necessary for on-duty tests). The RFID size is selected according to the maximum allowed distance of the reading/writing antenna; presently 20x40 mm tag, for the 100 mm distance. The 13.56 MHz transmission frequency is chosen, with the ISO/IEC 14443 transmission protocol.

The example prototypal set-up is, by now, an atypical issue, with, perhaps, fancy academic flavour, when the demanding economical terms of the competing manufacturing enterprises are considered as instant requests. The situation is deemed to change, as soon as the eco-consistency of the products put in the market becomes preliminary requisites, with charges incorporated among the enterprise duties. The carmaker responsibility of the product lifecycle operations, today, implies two orders of concern:

- to accomplish the free take-back of the end-of-life vehicles, ELV, and to assure given mandatory targets for the recovery (reuse, recycle) to lower the pollution and to spare virgin raw materials;
- to grant pre-set ecologic performance on operation life and associate to each product, the maintenance and healing prescriptions, so the environmental impact is kept within the enacted limits.

The competition between carmakers is destined to turn from the focus on the price at the point-of-sale, to the charges at the end-of-life, because of the compulsory rules directly forced, and along the on-duty operations, because the higher onerousness as compared with parallel offers will move off the market the lazy producers.

The most advised manufacturers, thereafter, are compelled to expand the lifecycle visibility of the sold items, according to two lines:

- the PLM-RL, to gather proper information in view of privileging the (most conservative) «reuse» track, as second instance, the «recycle» track when the secondary materials allow proper reliability, and addressing the thermal processing as residual option (due to the EU enacted restrictions);
- the PLM-SE, to expand the product-service delivery trend, today promoted by voluntary agreement rules, having the twin scope to reduce the on-duty environmental impact and to lengthen the items lifecycle, with resort to the whole transparency of the operation current and cumulated data.

The discussion on basic feature of the example instrumental set-up has, accordingly, the scope to anticipate what is believed to become standard practice, in the near future. The focus on a structural component made in plastic, as mentioned, is not without purport. The (first choice) «reuse» track cannot be done, unless the full reliability of the component is warranted, and the information has to appear in the PLM-RL data-base as standard opportunity. Moreover, the effectiveness of the service delivering can only be achieved, whether the items history is lifelong accessed, with the all sensible data. Now the driver's style cannot be figured out if the pertinent knowledge is left out; as it mostly bears, only, empirical evidence, the instrumental set-up plays the critical role, and needs to be properly devised.

The instrumental set-up, according to above shortly sketched lines, is developed with in mind the emerging demands in terms of the manufacturers' extended responsibility, with unequivocal involvement in the reverse logistics and in the re-engineering tasks, and relevant engagement in the service engineering, as the explicit origin of the product data, or, with higher commitment, as the direct provider of the lifecycle backing. These new facts require rethinking the competitiveness paradigms of the automotive industry, and, of course, object of special concern among the world-wide car-makers. The instrumental set-up, moreover, is also worthy help in assessing the users' behavioural accountability, with several falls-off. The lifecycle monitored data supply objective checks whether or not the driver has operated with full compliance of the manufacturer's notices or warnings and the law rules or instructions. The achieved transparency is important for the contractual bonds and the third-people protection, providing clear access to the users' liability, in case of accidents, when, e.g., the assurance is required to have objective reports on the elapsed occurrences, with resort to the records that document, in the present example, if, when, how long and by which trend the pedal is actuated.

4. THE EXPERIMENTAL INVESTIGATION

The virtual instrumentation investigation is accomplished as preliminary assessment of the experimental set-up. The analysis is separately performed, distinguishing the basic functions required to compute and to store two kinds of knowledge, namely:

- the short-term data (acquisition task), providing more details on the on-duty conditions and on the operation modes of the components, which, due to their redundancy, need to be vaulted into external archives and saved at regular time intervals;
- the long-term data (processing task), supplying synthetic features on the component current life, which are written on the RFID, and shall go along with it to characterise the cumulated properties.

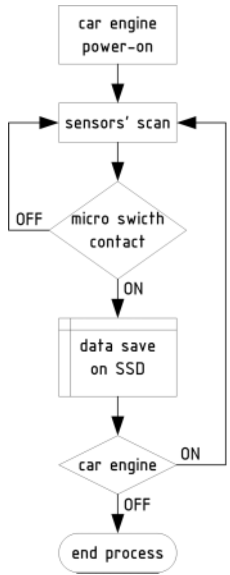

Figure 3. The acquisition task flow chart.

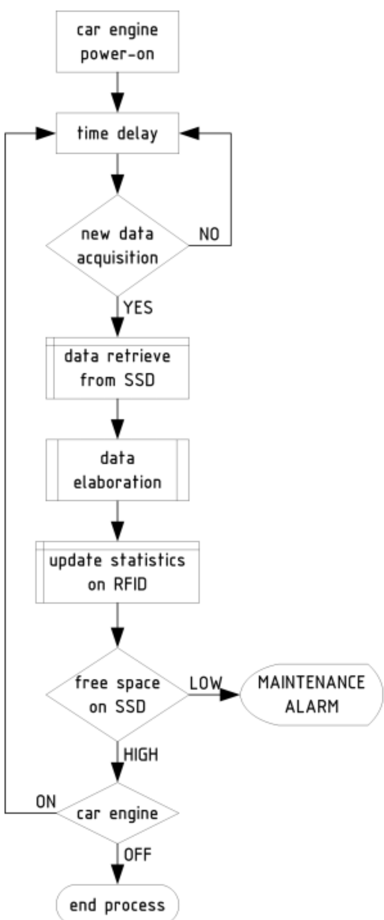

Figure 4. The processing task flow chart.

The acquisition and processing tasks are, at the same time, sequential and independent, that is: the data are acquired and stored, then the processing task starts on the stored data, but the detection task could start again, without waiting the end of the processing one. The independence between acquisition and elaboration grants the data storing even when the driver is quickly actuating the brake pedal several times.

The previously mentioned sensors send to the acquisition board a set of five analogue signals and one digital signal. All signals are acquired with 1 kHz scan rate. During the acquisition the data are saved on the SSD, with cycle time of 100 ms; the short delay, between data-acquisition and data-saving, protects against data loss in case of car accident. The flow chart of the tasks is given by Fig. 3. When the processing task starts, after the end of acquisition one, the device fetches the stored data from the SSD, and computes the requested features. The flow chart is shown in Fig. 4. To update the RFID-saved statistics with new data, the old ones shall firstly be read, from the RFID.

The Fig. 5 provides the pseudo-code listing of the example statistics computation. The specimen is provided as example explanatory opportunity, and additional processing might be included, whenever these features result useful. In sequence, the average actuation time T_{act}, the average force F_t, and the average acceleration A_{act}, and related variances, are computed, using the data from the on-board switch and counter.

```
T_new = T_stop - T_start;                    % present actuation time
T_old = T_act * N_act;                       % total actuation time
N_act = N_act + 1;                           % number of actuations
% Average actuation time (T_act):
T_act = (T_new + T_old) / N_act;

var_T_new = (T_act-T_new)2;                  % compute present time variance
%Time variance (T_var):
T_var = (T_var * (N_act – 1)+ var_T_new ) / N_act;

F_new = Sum_t (F_t);                         % present total actuation force
% Average force (F_act):
F_act = (F_act * T_old + F_new * T_new ) / T_act;

var_F_new = Sum_t (F_act-F_t)^2;             % present force variance
% Force variance (F_var):
F_var = (F_var * T_old + var_F_new * T_new ) / T_act;

A_new = Sqrt (A^2_x+A^2_y);                  % present actuation acceleration
% Average acceleration (A_act):
A_act = (A_act * T_old + A_new * T_new ) / T_act;

var_A_new = Sum_t (A_act-A_t);               % present acceleration variance
% Acceleration variance (A_var):
A_var = (A_var * T_old + var_A_new * T_new ) / T_act;
```

Figure 5. Pseudo-code for the statistics computation.

5. CONCLUSION

The example case-investigation, discussed in the paper, permits to sketch the incumbent requirements, now pending on the carmakers, but readily to be extended to the many other manufacturers of consumables and durables. The devised experimental set-up offers factual help to create the essential lifecycle data acquisition and vaulting. To correctly tackle the resource recovery policy, in fact, binding prerequisite is the knowledge about the item (or complex system) condition, at any specific time mark and of its cumulated history since the manufacturing stage. These data heavily impact on the economic evaluation of the resources productivity and of reconditioning operations and, consequently, on the decision whether the reuse-recycle of the item is appropriate or not.

The focus on the recovery (reuse, recycle) opportunities, today already ruled by mandatory EU targets, is, however, only partial achievement, whether limited to the build-up of the PLM-RL data-base. The growth sustainability is similarly affected by the availability of detailed PLM-SE data-bases, to be intensively used along the on-duty exploitation of the product for the servicing business, and by the original manufacturers for up-grading the current offers.

The practice of design-for-restoring, -for-maintenance, -for-dismantle, -for-recycle, etc. is producer's duty, to improve the conservativeness. This leads to the some shrewd features, such as: self-tuning ability, when disturbances off-set running requirement; pro-active maintenance, based on the monitored indices; schemes for tangibles call-back or final withdrawal, linked to actually assessed work-conditions, etc., showing that the monitoring is inherent commitment, as the designers' responsibility needs to cover the all duty-cycle. When the concern on the eco-responsiveness increases, special purpose design choices appear, as generic hints:

- planning for quality protection of the used items, easy disassembly, material reuse, etc.;
- designing for long-life availability, rare maintenance, low energy consumption, etc.;
- preferring self-tuned rigs, high yield applications, re-used packaging, improved logistics, etc.;
- setting optimal on-duty effectiveness, pro-active up-keeping, etc. extended artefacts;
- choosing high throughput, material saving, energy recovery, etc. operation processes;
- making extensive use of recycled, less energy-intensive, renewable, etc., materials;

either, these betterment choices are introduced as specific recovery options:

- re-conditioning, say, to back establish the original conformance to specification, by combined industrial processes applied at the life end of the artefacts; re-conditioning is limited, if the re-setting is partial;
- re-manufacturing, say, to recover parts and material matching original properties, by combined industrial processes applied to dismissed artefacts, and to candidate them to new duty-cycles; the issue is limited, if the processed parts do not recover the original characteristics.

All in all, according to the outlined considerations, the lifecycle monitoring frameworks happen to become the emerging opportunity that the tomorrow manufacturing industries are compelled to explore, to enhance the competitiveness, with increasing rate, while their responsibility expands, from the point-of-sale, to the point-of-service, after incorporating the free take-back of the end-of-life goods. The case example discussed by the paper, thus, rather than episodic attainments, shall be considered standard achievements of the new, more eco-conscious work-organisations, assuring a future to the industrial economy.

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