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A TRIZ-BASED METHOD FOR SMART PRODUCT DESIGN

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Abstract: *The business environment of last year's imposes to manufacturing firms to offer digital and/or smart products. This is a market pushing trend the manufacturers cannot fail to answer. Unfortunately, digitize a non-smart product might entail significative costs due to production process changes. To minimise this, Warrant Innovation Lab developed a method based on second and fourth laws of technical system evolution, the energy conductivity law and ideality law, to easily identify what are the key elements on which focus the digital-innovation project. It exploits the energy streams that run throughout the system and the elements they involve, depicting them in Energy Chain Maps. The method and tool result extremely easy to be used and very effective in identify the key elements by which digitize the system.*
Key words: *Energy Chain Map, Product Digitization, Smart Product, Second Law of Technical system Evolution, Energy Conductivity Law, Energy Streams, In-formation Streams.*

1. INTRODUCTION

Smart products are more and more present in the real life. In recent years, nation-al and regional funding has pushed investments on advanced manufacturing and it is going to continue this trend [1]-[2]. Industry 4.0 is acting as an innovation-driving topic not only on technology, but also on business models [3]-[7]. More than manufacturing processes improvements, digitized and smart products, i.e. products relying on Cyber-Physical System (CPS) paradigm [8]-[11], could open new perspectives for SMEs [12]-[15].

Unfortunately, CPS is not always synonym of ideality. Nonetheless, often the offering of smart products is a must-to-have in 2020, that means development of digital and/or smart products acts like a pushing trend imposed by the market, to which the manufacturers cannot fail to answer

As digitized/digital products the author means objects able to generate and transmit digital signals, e.g. by the transduction of a physical quantity into an electrical signal and discretizing it before sending it to a controller or a data col-lector. Whilst as smart products, he refers to objects that provide at least a first data computation on-board, before transmitting digital signals. E.g. an IoT sensor that, measuring vibrations of a machine organ, can determine the machine status and send to the controller only, or also, the machine status as good, pre-warning, warning, and/or critical stop.

Some methods and methodologies have been proposed to support the design of smart products [16]-[22] and there are many companies that work in digitization and smartization of existing products. However, they mainly focus on how to effectively integrate the physical system and the cyber model or how to find the new exploitable value from this kind of integration. Nonetheless, there is a lack in structured method that pursue the minimization of production process change costs generated by the digitization or smartization of existing products

This article introduces the TRIZ-based approach developed by Warrant Inno-vation Lab S.r.l. (WIL) to support its customers to deal with digitalization and/or smartization projects. It relies on the effectiveness the second law of technical system evolution has in working with measuring systems [23]. Through this way, WIL expands its TRIZ-based service offering [24]-[25], aiming to support Italian SMEs in pursuing the ideality of their systems, minimizing changes of basic not-smart product, limiting the impact on production process, then costs.

The next section describes the simple assumptions on which the approach establishes its structure, the correlation between information and energy exchanges. Then, 3rd section presents a tool as a new interpretation of the well-known TRIZ tools Functional Analysis and Minimal-Technical-System (MTS) [23] and the way to use it to pursue the minimization of production process changes.

Section 4 describes the usage of what just explained in a case study about dig-itisation of lifelines. The author chose it because of its current totally mechanical operations, without any communication features. Finally, Conclusion section summarizes the most interesting aspects

2. INFORMATION LIKE ENERGY STREAM IN THE SYSTEM

A smart product relies on the so-called Cyber-Physical System (CPS), a strong integration between a physical system and its cyber model [8]. Often, it happens that SMEs can rely on strong expertise about physical object, but they lack in information and data management, knowledge about mathematical modelling and algorithms, or IT skills.

The choice of what and how to gather data from the product to make it smart or digital is not a trivial one. Nonskilled technicians might fall into errors generating a high risk of failure of the project. Nonetheless, expertise on current system is extremely important to correctly define what should be monitored and which could be the appropriate feedback from the model. WIL helps SMEs to direct their expertise toward a conceptual solution that collects all useful information to scouting potential technology and/or knowledge providers.

The method bases on a simple assumption: the information the user wants to extract from the system runs inside it as energy stream(s).

According to what stated by the second law of technical systems evolution [23], the energy conductivity law, the system can be depicted as a chain of elements linked themselves by one or more energy stream, a sort of energy chain. More, each element in the chain converts energy and then transmits it to next element(s), including environment outside system boundaries.

Thus, to gather the desired datum from the system it is enough to catch the energy stream and measure or transduce it from, at least, an element included in the related energy chain. Relying on desired data collection, the system provides useful information.

3. ENERGY CHAINS AND KEY ELEMENTS

The method WIL proposes aims to pursue ideality, according to what stated by what fourth law of technical system evolution [23]. In digitization of existing systems, it means to minimize the cost of the transition to a digital or smart prod-uct. To do this, the method guides its user in finding the most befitting elements from which catch the most interesting information about their systems, leaving the others unchanged.

As just explained, energy streams bring information throughout the energy chains. Thus, tracking the energy linkages between elements, of course consider-ing exchanges through fields also, the user can trace the elements involved in any information stream.

There are many kinds of information that run throughout the system, then many chains to be tracked. Not all the elements are included in any stream, but there should be some elements involved in a large part of them. Exploiting the convergence of energy streams, the user can easily find the most befitting ele-ments for digitize the system. Here, on these key elements, the information can be caught by opportune sensors/transducers.

3.1 Depicting Energy Chain Map (ECM)

If information is carried by an energy stream, depicting the system as a chain of elements linked themselves by energy exchanges lets the user of the method to easy identify which are the elements of the system involved in the information stream.

The schema can be compared to a functional analysis and MTS [23]. The first sketches elements linked themselves through functional interactions; replacing functional interaction with energy exchange, the result is an Energy Chain Map (ECM) that shows the set of elements involved in an information stream inside the system. In case of MTS the ECM could be considered as the explosion of the transmission block. Fig. 1 shows an example of a generic ECM compared with both functional analysis and MTS.

Like the functional analysis, also the ECM is 'static', in fact, it illustrates a steady configuration of the system. To represent other arrangements, e.g. system set-up during maintenance, a new ECM is request.

Compared to MTS, it reaches a deeper detail in system description. Like MTS, it can keep in the schema also the source and the tool blocks, and sometimes the object-product transformation, to help the customer in better understand what the energy chain refers to.

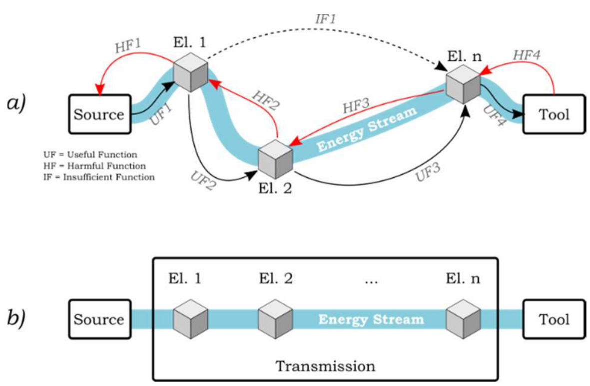

Fig. 1. Comparison of ECM with a) Functional Analysis and b) MTS

Often, it happens the customer need help in digitize a passive product, that has no inner energy source required to work. This is the case of the case study, presented in the section 4, about a lifeline, i.e. a safety system for roof works.

In these cases, it is crucial to understand how the information the customer wants to catch is involved in the system and which are the events that should generate the concerning energy streams through the system.

Thus, when the user faces a request to digitize a passive system, he/she can con-sider the ECM anyway, keeping in mind to take the transformations that refers to the events like energy sources, and tracking the elements of the system involved in their streams up to the output of the system.

3.2 Information convergences

Any product/system might work in different conditions, e.g. nominal operation, process drifts, maintenance, warm-up, emergency and so on, to which a different set of elements might match.

Furthermore, the request of information coming from a kind of user might be very different from the set of information needed by another type of user or by the manufacturer, e.g. for remote diagnostic/maintenance service.

This means that more than one ECM should be drawn during the analysis about information streams of a product digitization project. All of them collect a subset of system's elements and tracks the information streams as energy ones.

To pursue ideality, the method drives the user to find the system element(s) in which all interesting information converge. The author calls these elements Key Elements. They are the most befitting elements for digitize the system and they can be easily found by overlapping the ECMs and looking for the intersection elements, see Fig. 2.

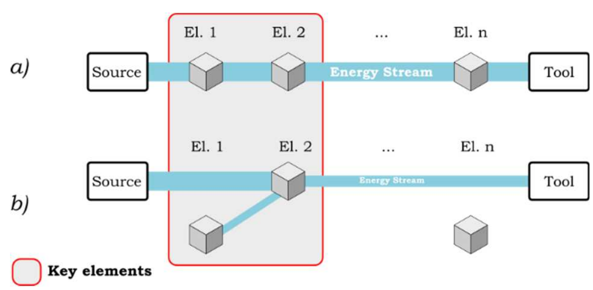

Fig. 2. ECMs for different arrangements of the same system: a) nominal operational arrangement; b) secondary arrangement; elements involved in both streams are the key elements to digitize the system

Fig. 2 compares a nominal arrangement, a), in which all elements of the system are involved in the main energy stream and a secondary arrangement, b), where Element 1 belongs to a secondary stream and Element n is avoided by any energy stream. Overlapping the two ECMs, it is easy to identify Elements 1 and 2 as the Key Elements to digitize the system.

When more than one key element is available, the ideality suggests choosing the simplest one to be digitized. Among the key elements, the user can choose it considering the ownership of the element (it might be a commercial product not modifiable by the supplier of the system), impact on production process, availability and cost of the sensing technology, strategic impact for product marketing, etc.

However, it might happen the elements on which digitize the system are out-side from the system. In this case the analysis could proceed considering which are the external resources the environment offers to sense it or move the focus of the project on the second placed elements inside the system.

3.3 Geometrical issues

Among the most interesting information to get from a digitized system, there are localization of the system, its presence in a defined area or gate/boundary crossing. These kinds of information refer to sensing of geometrical quantity that, generally, do not involve energy exchanges, thus no energy streams are available to carry the information through the system.

In this case, the system itself cannot define the output, it needs an external reference. The user of the method should consider which resources the environment might give to sense the geometrical quantity the user requests.

To face the extraction of geometrical data, ECMs' convergence should be considered as a list of available and appropriate inner resources, the key elements, to be used to interact with external reference system. Of course, only key elements included in the system arrangement at the time of geometrical data sensing should be considered.

4. CASE STUDY: DIGITISING A LIFELINE

For one of WIL's customers, which is a European leader firm in the field of safety systems, the author led the service for product digitization, according to what described above. Between products supplied, it offers lifelines, which are, currently, strictly mechanical systems. Above all, lifelines are non-strategic systems for the end user, but a cost imposed by labor safety laws. The market looks for the cheapest solution that comply the laws and let the end user free from thoughts about it.

The lifeline is a very effective solution able to save the roof workers form death due to falling. However, in this case the response time is a crucial factor because the common harnesses leave to the worker about 20 mins before his/her suffocation death. Sending a call for emergency rescue is not a crucial problem when operators works in little plants: the likelihood that somebody hear or see them falling or dangling in brief time is high.

The response time might be a problem in case of large plants, where there are many buildings, then roofs, generally with different heights from the ground lev-el. In those plants the number of lifelines installed can reach one hundred and more on many square meters of roofs. Also considering restricted access to the roofs to at least a couple of workers, it is impossible for the plant safety manager have the situation under control. In case of falling, or other risky happenings, is difficult to ensure a prompt response. Furthermore, the localization of the event is not so easy to determine and communicate to the rescue team. This information could be crucial to determine which way of access to the plant take, it might save some minutes; thus, localization might decide between life or death.

For the supplier, the communication feature could be a strong deal for market-ing and operations. It would let it to provide a fast alerting service more than safety operations. However, the system cost remains the greatest limit.

4.1 Most interesting information

WIL proposes a TRIZ-based method which focus on minimize the cost of production process changes. To be effective the method starts defining which kinds of information the system should generate.

Contrary to functional requirements, often information is not the core business of our customer. To ease the definition of desired data, WIL employs a structured approach to enhance the effectiveness of customer interviews. It surveys first what the system does, its functions; then, where it should work to define which are the operational environment; finally, who are the stakeholders of the system. From functions it arises the set of interesting information to monitor the work of the system, whilst from environment comes information about life cycle and available resources. The stakeholders are whom to which should be addressed the information, once more adding a new set of interesting data.

In the case of lifelines, more than falling happening, the safety process involved in roof working activity starts in the safety manager office, who gives the safety equipment to workers. Then, workers go upstairs, access to the roof, clasp the equipment to the anchoring cable and start the operations. At the end of the job task, they repeat the steps in counter wise order. It easy to understand that the process just summarized includes different scenarios. As well, the stakeholders are more than workers. They include the plant safety manager, the operation or safety manager of the company, the CEO who has the final legal liability, the worker employer, and the lifeline supplier. All of them needs different information or different level of the same information.

The amount of data to be collected, at this point, may be very large. To focus the development on most attractive features, the activity exploited the Market Potential tool [26, 27]. Among most desirable information to sense are included:

- Occurrence of worker falling;
- Check of carabiner clasping on anchoring cable;
- Worker roof access/presence

4.2 ECMs and key elements

Once set of main information is defined, it is crucial to link information and related energy stream.

In functional terms, to stop the falling the lifeline system must waste the kinetic energy due to gravity acceleration. Thus, the source of energy is the falling human. Then, the energy runs in all elements of the lifeline: harness, safety lanyard, carabiner, steel cable, damper, anchoring means, anchoring plates, and roof. All of these elements are available to sense the falling and start a safety alert.

To check whether the worker clasps to the lifeline the useful elements are the carabiner in the hand of the worker, the steel cable to which the carabiner should lock, and the safety lanyard fixed to the carabiner. Even in this case, the action is performed by the worker who introduce energy in the system.

Fig. 3 shows two arrangements of the lifeline to whom are linked some kinds of information and which type of energy stream could be exploited to catch related data.

According to what explained in section 3.2, by overlapping ECMs the user of the method can easily get the set of key elements. In the case study, Fig. 3 high-lights Safety Lanyard, Carabiner and Steel Cable, i.e. those involved in energy streams of both arrangements.

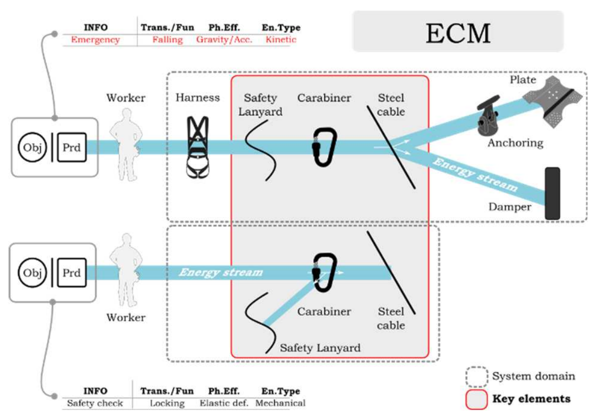

Fig. 3. ECMs and key elements identification for a lifeline in nominal operation arrangement and in clasping phase

4.3 Key elements as resources for roof access detection

The customer requires to get a check when workers access to the roof. It is a geometrical case because the system should sense the position of the worker, defining if he/she is inside roof boundary or outside.

According to what described in section 3.3, this kind of transformation lacks in direct energy stream running inside the system. Rather, it should sense the result of an external transformation, i.e. worker going upstairs or walking though roof access gate.

In case study, the access to the roof is by a ladder, as shown in Fig. 4. It depicts the situations before and after the roof access. When workers accesses to the roof, the lifeline system involves only wearable elements, Harness, Safety Lan-yard and Carabiner, whilst anchored elements are still 'far' from the worker.

Within wearable elements, Safety Lanyard and Carabiner are the two included in the set of key elements, as highlighted in the figure. These are the ones on which the method suggests working to sense the roof access. They are the internal resources available for the interaction with external one, i.e. the ladder, which could be exploited as fixed reference to discriminate between inside and outside.

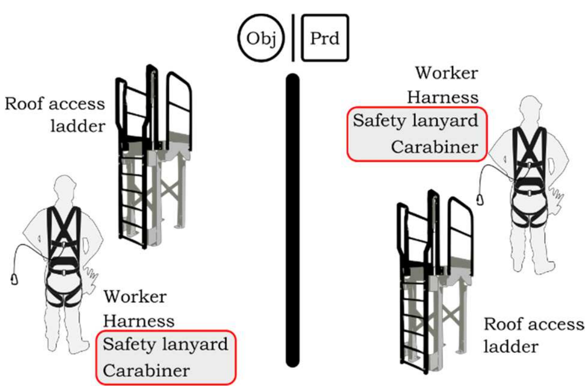

Fig. 4. Object-product transformation about the roof access of the worker through a ladder.

4.4 Case study results

The basic assumption on information, i.e. the energy stream conveys it into the system, let the customer to modify its point of view about the lifeline system and information it can provide. As a first result, the customer found new kinds of interesting information it could catch from the lifeline. More, interpreting information as energy stream, the customer found it easier to understand how to get the information, i.e. what transformation transduce to collect desired datum.

Depicting each ECM helped the customer to visualize the lifeline system in the correct scenario for each kind of information sought. Doing this before the definition of the sensing technology avoid it from adapting the sensing technology to unexpected scenarios. Rather, they guided the customer to select the better technology able to work in all relevant situations.

Even about the geometrical problem, access to the roof, the method gave a benefit. Setting the element of the system by which digitize it, the customer changes the point of view about interaction with external resources. Whereas before it was looking for a way to sense the position of the worker on the roof, now it focuses on an interaction between a wearable element and an external re-source able to define the boundary of the roof, like the ladder.

Furthermore, to complete the innovation project in which the method was used, the customer applied for a patent to protect the conceptual solution achieved.

5. CONCLUSION

The business environment of last year's imposes to manufacturing firms to offer digital and/or smart products. This is a market pushing trend the manufacturers cannot fail to answer. Digitize a non-smart product might entail significative costs due to production process changes. To minimize this, WIL developed a method based on second and fourth laws of technical system evolution, the energy conductivity law and the ideality law, to easily identify what are the key elements on which focus the digital-innovation project.

The method guides the user in finding the elements on which the convergence of the information streams occurs. From these, the most interesting information about the systems can be collected considering the opportune sensing mean, avoiding change of other elements.

The approach bases on the assumption that information runs inside the system as energy streams. Each of them passes through a subset of elements, the energy chain, that can be compared to other chain of other information streams. Elements shared by the largest part of streams are key elements. Considering the convergence of the streams on key elements, the method focused the effort on digitization of a single element, conveying in a hidden way the ideality of the digitization: it minimizes the impact of digital transition on production process.

Energy Chain Map (ECM) is defined as a new tool for this specific task. How-ever, it describes the energy streams throughout the system related to a function making. Thus, ECM is available any time there is the request to track energy streams.

The method and tool are extremely easy to be exploited and very effective in identify the key elements by which digitize the system. More, they can support analysis also in case of geometrical data where data request cannot be linked to an energy exchange inside the system.

Moreover, additional information could be collected and linked to the results, like energy conversion made by key elements or environment resources available when manufacturer cannot modify key elements. Those are definitely useful to well-define the next development steps, e.g. conceptual solution or technology/knowledge scouting.

The ECM tool needs further development to concern with transient phenomena. The ECM represent a steady set-up of the product and do not provide dynamic features. Currently, when time scale matter, wave effect on energy flow is depicted like harmful action in functional analysis to keep it in mind during the subsequent analysis.

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Metodă bazată pe TRIZ pentru proiectarea de produse inteligente

Rezumat: Mediul de afaceri din ultimii ani impune firmelor producătoare să ofere produse digitale și / sau inteligente. Acesta este un trend care împinge piața, trend la care producătorii nu au răspuns. Din păcate, digitizarea unui produs care nu este inteligent ar putea implica costuri semnificative din cauza modificărilor procesului de producție. Pentru a minimiza acest lucru, Warrant Innovation Lab a dezvoltat o metodă bazată pe a doua și a patra lege de evoluție a sistemului tehnic, legea conductivității energetice și legea idealității, pentru a identifica cu ușurință care sunt elementele cheie pe care se concentrează proiectul de inovație digitală. Acesta exploatează fluxurile de energie care rulează în întregul sistem și elementele pe care le implică, prezentându-le în Hărțile Lanțului Energetic. Metoda și instrumentul sunt extrem de ușor de utilizat și foarte eficiente în identificarea elementelor cheie prin care se digitalizează sistemul.

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