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Product-Service Systems across Life Cycle

FIT: a TRIZ based Failure Identification tool for Product-Service Systems

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Abstract

Manufacturing companies are increasingly becoming aware that the sale of a product does not end when the good is delivered to the customer. On the contrary, the product must be followed by the company throughout its life cycle; from its conception to its disposal. An increasingly common practice is to support the entire chain of sales and after sales, from dealers to end customers, with a range of services that give the product added value. For example in the field of crane manufacturers for trucks, Fassi Gru S.p.a. provides, in addition to its product training for the use and maintenance of cranes, tools for the simulation of the lifting capacity of the crane (Fassi Installation Program), monitoring of usage statistics and the state of wear of the crane (Fassi SmartApp, Internet of Crane™), control of residual life, and the status and timing of maintenance (Maintenance Assistant). The work presented here is a new after sale service designed to identify quickly and easily the element that caused the failure of the crane through a series of guided questions about the behavior of the crane subject to malfunctions. This tool is called FIT (Fault Investigator Tool) and allows the network service Fassi rapid and accurate diagnosis of the cause of failure in case of malfunctions of the crane; reducing the time to diagnosis and avoiding unnecessary and costly replacement components by trial and error. The novelty of this work lies in the method used to achieve it; FIT was in fact created by the special knowledge gained from R&D engineers of Fassi about new methods of systematic innovation developed by the University of Bergamo. In this article some of these techniques are shown: in particular those dealing with the correct formulation of the problem, the functional analysis and the Anticipatory Failure Determination; a particular instrument that combines FMEA (Failure modes and effects analysis) and TRIZ (Theory of inventive problem solving). The article will also present the needs that led to the development of the tool and show the operation of the instrument through a case study; showing all the advantages provided by its application.

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Keywords: Service, Maintenance, TRIZ, Functional analysis, AFD

1. Introduction

The PSS (Product-Service Systems) concept was conceived from an innovation strategy. The aim of PSS is shifting the business focus from product design to a more complex system that goes beyond the mere designing and manufacturing.

According to Tucker classification [1], PSS includes three main categories: (1) product oriented services, offered by the company to the consumer when it acquires the product in order to add its value, (2) use oriented services, when the property of the product remains the company offering its use (i.e. car sharing), and finally (3) results-oriented services, when only the result or a competency is sold to a consumer (i.e. selling washed clothes instead of washing machines).

Among all product-oriented services, those related to product maintenance are crucial to increase the competitiveness of the product. In fact maximizing the use of a product along with its maintenance, the PSS prioritizes the management of the system for the product life cycle [2-3].

One of the most popular method at the industrial level suitable for facing maintenance problems is Failure Mode and Effects Analysis (FMEA) method. It has been developed in order to identify failure mode and defect of a process, product or a system. U.S. military developed FMEA in 1949 and in 1960s NASA used it for the Apollo lunar mission [4]. A big

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boost to the spread of the method was done by the American automotive (General Motors, Chrysler and Ford), which has strongly believed in it since the 80s and has successfully applied it in different fields like design, manufacturing, quality management, and suppliers evaluation. A major contribution to the definition of FMEA for automotive industries was given by: Stamatis [5], Leung et al. [6] and Albuquerque et al. [7].

Despite the great potential FMEA can offer to create new services on maintenance, in literature the combination of FMEA and PSS is not widespread. Only recently, there have been some interesting attempts to integrate FMEA in a PSS by a structured approach. In 2013 Chen [8] combined FMEA technique and Importance-Performance Analysis (IPA) to identify critical customer needs, while Zancul [9] used FMEA for identifying what should be monitored in the product to minimize potential product failures.

Herein, the authors present a FMEA application to support maintenance PSS: a new software tool for the diagnosis of the cause of failure in case of malfunctions of a crane.

2. A PSS tool integrating TRIZ and FMEA

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.

The evolution of FMEA is characterized by a continuous adaptation to various fields of application. Although the method is highly structured and systematic, the continue modifications suggest that it has not peeked it evolution yet. For this reason, this paper present a FMEA version integrated with the theory of inventing problem solving (TRIZ) [10]. TRIZ is used in order to simplify the process and make it more robust the problem solving task. The entire methodology was developed by Russo [11,12] with the aim of ameliorating the efficacy and efficiency of classical FMEA during product development; it is here applied for a different purpose dealing with the ideation of a new maintenance PSS tool.

This is not the first time that TRIZ fundamental and tools are used within the PSS. There are many examples where TRIZ has been successfully applied to services [12-17]. While the current application of TRIZ in the SS o PSS context is limited to its core concepts, as the 40 inventive principles, Regazzoni [18-19] proposed a way to improve PSS by using the Laws of Technical Systems Evolution (LTSE) and the Evolution Trends while Mann and Jones [20] proposed a paper on the development of sustainable services and systems through the adoption of systematic innovation methods.

For better introducing the application of TRIZ to this approach the problem solving process has been divided into two parts: the problem definition phase, and the investigation of possible solutions.

Similarly, it is possible to deconstruct the failure identification process. In fact, it is a specific application of the problem solving process, where we search not for the problem resolution, but rather aim at identifying the failure.

In both phases, it is important to follow a methodical and systematic process, by first reformulating the problem, and then solving it. The lack of a codified procedure in failure or problem analysis leads to the direct research of its solution. This is typical of the trial and error method that, especially in failure solving, leads to solve malfunction through the disorganized replacement of product components. This negatively affects costs and time of failure solving. Moreover, the lack of a systematic and guided process likely involves running into the formulation of problem solutions within one’s own technological background (a chemist will tend to see and investigate chemical problems, a hydraulics expert oleo dynamic issues, an electronics expert electronic problems). This behavior is called psychological inertia.

An instrument (FIT, Fault Investigator Tool) has been developed to avoid this type of process and allow Fassi service network to rapidly and accurately diagnose the failure cause in case of crane malfunctions. In this way, time for diagnosis is reduced and useless and expensive trial-and-error interventions of component replacement are prevented.

FIT internal database includes all the possible failures that may occur to a crane and guides the user through a limited series of questions to the identification of a restricted list of elements that may constitute the malfunction cause. In brief, the user is guided in delineating the failure by a dialog-based system. In this manner, customers are provided with an efficient assistance service: on the one hand, it reduces the machine downtimes due to useless replacements of several components; on the other hand, it avoids waste of money both for customers and, in case of warranties, for Fassi.

3. FIT’S Background

FIT has been developed to speed up diagnosis of Fassi cranes faults. The main problem was the time to repair the crane. It is highly dependent on the personal skill of the maintenance staff. It has been proved that people experienced in a certain domain (i.e. in hydraulic or electrician) goes to seek for first the cause on its own domain, even if the problem is clearly outside. Even the most experts do not use any kind of structured approach. Maintenance staff is not totally under Fassi control, so it is much easier to develop a tool that limits trial and error during maintenance, rather than investing in the staff training. In addition, the system also can benefit the user of the crane in properly report the fault to the service, so increasing the efficiency and the degree of client retention.

To develop FIT it was necessary to combine some fundamentals of TRIZ, and adapt them for a new systematic approach. The following is a list of these TRIZ tools. The starting point was the functional analysis.

Functional Analysis

Research on functional analysis has produced several representational formalisms, e.g. the Function Tree (Value Analysis Incorporated 1993), the Data Flow Diagram (Yourdon 1989), and the Function Structure (Pahl at al 2007).

The common concept underlying the different schemes is the determination of the overall function of the product under analysis and the mapping of all the sub-functions that represent the interactions present in the system. However, the concept of function is often elusive and varies from model to model. Thus, the representations differ because of their components and the way they are organized.

The first theoretical scheme on mapping of useful and harmful actions between the components of a product and between the product and the users was originally published as part of a patent application filed by TRIZ.

A function diagram gives a snapshot of all the functions that are important to the job. Many of these functions are not obvious when we look at the system from a process perspective, but appear only when filling out the diagram that forces the user to thoroughly dissect the System.

During the analysis the designer identifies not only the useful functions, namely those of the project, but there are also other functions that are not useful to the purpose for which the product was designed, or even harmful.

For the construction of FIT, the classic use of the function chart has been reinterpreted. Starting from the functional diagram of the Fassi crane in nominal project conditions, a series of alterations were produced, in a systematic fashion, for each component. The resulting negative effects are then mapped to on the functional diagram. In this way it was possible to identify all failure modes (real and potential).

In order to strengthen this technique the authors combined it with another technique, called Subversive Analysis.

Subversive Analysis AFD

AFD guides users in documenting the situation, formulating the related problem(s), developing hypotheses, verifying potential failure scenarios, and finding solutions to eliminate the problem(s). The Main Idea of Ideation Failure Prediction: Problem Inversion.

Change perspective from: – “what happened to cause the failure” or; – “why did the failure occur” to “how can we create or invent the failure”.

Many of the TRIZ tools that are usually used to generate ideas and find solutions (inventive principles and standard solutions), have been integrated into the proposed method to produce a failure. The majority of faults on a product of the kind occur without any outside intervention. In TRIZ terms and following the logic of subversive analysis we could say that the system is usually able to create the failure by using a resource available within itself.

Identifying these resources is another fundamental step that was used in the present work.

Resources

TRIZ resources is a broad concept which encompasses many resources which are generally not visible or thought of as a resource. Some are paid for, such as electricity or heat, and other ones are free, such as air or gravitational pull. The TRIZ concept of resources was best defined by Salamatov: “*Resources are everything that remains idle in the technical system and its environment*”. Special attention is given to those resources that are commonly thought as negative (though the concept of a negative resource is an oxymoron) and that are avoided, or effort is given to reduce them. TRIZ on the contrary tries to use these resources and transform them into something useful.

When studying a problem, resources are not limited to its system and the components involved, but stretch to the entire environment; the past and the future of the system as well.

4. How the tool was conceived

FIT was designed to be used by Fassi technical assistance and dealers. Due to technical reason, actually it has been implemented only for diagnosing faults in production.
The tool creation is composed of two main phases: on the one hand, it is necessary to systematically search all the failures that may occur on the crane; on the other hand, it is necessary to identify a way to search them in the easiest and quickest manner.

The starting point for failure research is the functional analysis of the machine and its later disturbance. The aim is to map the crane correct working, stressing cause-and-effect relationships between components and then to voluntarily modify them in a systematic way. Complex assemblies, composed of hundreds of components, cannot be mapped simultaneously in a unique functional analysis. Thus, it is necessary to perform functional analysis on more levels of detail, starting from a general level and then going step-by-step into more detail. This deconstruction method enables an orderly analysis of a complex system, as well as the identification of the significant elements from a functional point of view. No long bills of materials are required.

The functional analysis, showing cause-and-effect relationships between the various elements, aims at pointing out and specifying the nature of functional connections between components (useful function, harmful function, insufficient function). In this way, the machine working is described from a functional point of view in its correct status; that is to say, without failures.

The second step is the voluntary creation of failures. Each functional analysis contains a primary useful function; every negative disturbance to that function is a failure that may occur to the machine. Therefore, failure identification is carried out by voluntarily causing disturbances in the cause-and-effect chains of functional analyses.

Contextualizing the approach described above, the first step is the identification of the primary function(s) of the crane as a single whole.

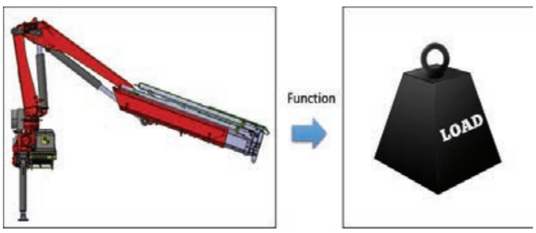

Fig. 1. Crane primary function

Later, the crane is decomposed into structural groups and the primary useful function is applied to each of them. The choice is made in favour of the main structural groups of the machine, as they are the input channel for FIT utilization and the user can identify them better than the functional ones.

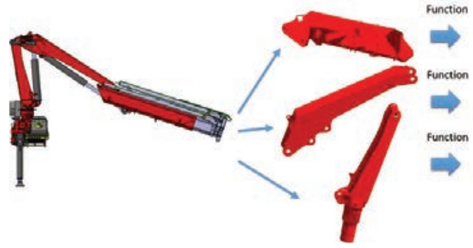

Fig. 2. Crane structural groups and their primary function

Then, each structural group is analysed functionally in a more detailed level than previously done.

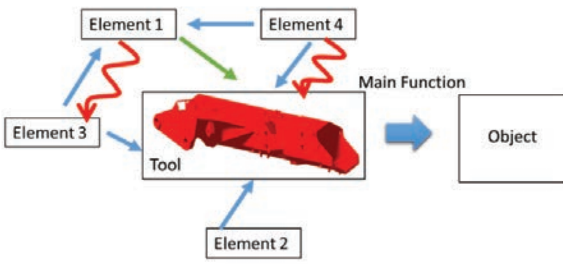

Fig. 3. Functional analysis of a crane component

At this level of detail, the first disturbance is carried out to the primary useful functions represented in the functional analysis: first, functions are annulled and then made insufficient and harmful; according to the concepts of function, anti-function and non-function (for instance, the car lock shall open, function; in case of theft shall not open, non-function; shall lock, anti-function).

Therefore, the disturbed primary useful functions turn into the aim to achieve. The aim is: *how is it possible to voluntarily cause malfunction?*

Fig. 4. Cause a voluntary malfunction

Two tools are used in order to identify the ways of obtaining the disturbed primary useful function through the variation of the functional analysis elements:

1) Resources within the functional analysis (obtained from the other elements composing the functional analysis).
2) Direct disturbance, managed by the P-Diagram, of the physical features of the functional analysis modelled elements.

Every resource or modified physical feature causing the disturbed primary useful function represents a possible failure.

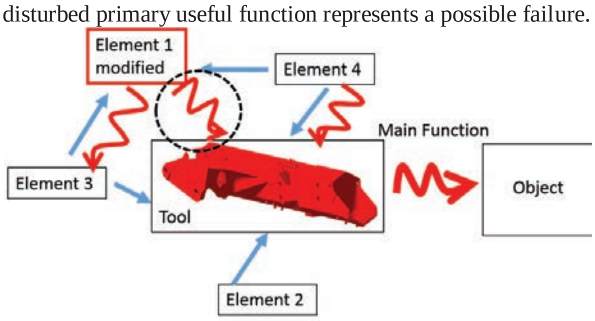

Fig. 5. Functional analysis: an element is modified to cause harmful functions

The functional output of the disturbed elements (they are disturbed one-by-one) is represented by a new harmful function (it is new in regard to the non-disturbed functional analysis), an insufficient function coming from a previously sufficient function, or a non-function ensuing from a useful sufficient one.

If the triad modified element – function – object (affected by that function) defines the failure mode clearly and thoroughly, that will represent one of the possible machine failure modes.

On the contrary, if the definition of the phenomenon is not exhaustive, or the modified element is a functional group itself, that triad will constitute the basis of a more detailed functional analysis. This functional analysis is disturbed as described previously and the whole process repeated up to the identification of all the machine failure modes.

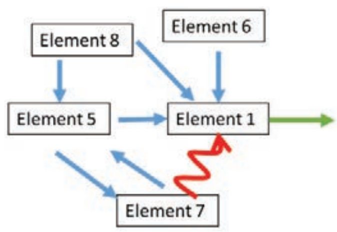

Fig. 6. Element 1 is expanded to analyze its sub-components

The second phase for FIT creation aims at the identification of a way for navigating and moving through the detected failures. The user shall identify in a simple way the failure causing the crane malfunction. The implementation of a dialog-based system has been considered the most intuitive solution, which could be easily recognized and used. In fact, this system asks the user some questions and, according to his answers, it offers him further questions.

Questions shall be effective, understandable, and with fast yes/no responses.

Effective, since every question shall sort the range of the available failures into two groups, as homogeneous as possible as regards quantity. With yes/no responses, as the division of failures into two groups shall require a couple of answers for each question. Fast, as the user shall answer a question depending on the detected malfunction, without carrying out further investigations. Therefore, the identified questions shall ask the user for clarifications about failure and observations of the crane performance.

The application of this failure identification procedure has revealed about 1500 failure modes for causing malfunction to the crane and about 150 questions for navigating those failure modes.

5. How the tool works

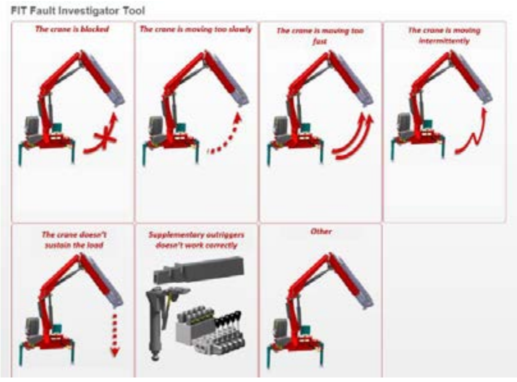

Fig. 7. FIT Fault Investigator Tool

FIT working follows the way it has been created. First, malfunction is described on a general level and then it is analysed and explained step-by-step on a more detailed level. The aim is obtaining a restricted list of elements on which the investigation can be focused.

First of all, the tool asks the user to indicate the effect he perceives from malfunction. The several choices the user can make are nothing more than the disturbed primary useful functions of the crane as a single assembly.

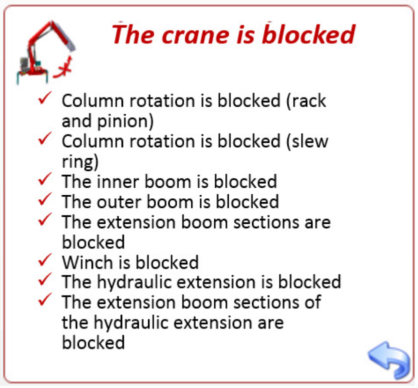

Fig. 8. FIT: The crane is blocked, symptoms

After the choice of the malfunction effect on a global level, FIT asks for the recognition of the structural group affected by that malfunction. Structural groups are those used for creating the tool.

If it is not possible to limit the malfunction to one structural group only, the user can choose any functional group affected by malfunction. After the choice, the tool interface changes to dialog-based mode. On the right, the user can find the questions he has to answer, while on the left the elements that may cause malfunction.

As the user answers the questions, the possible elements causing malfunction decrease and the process goes on until the user believes the number of elements is limited enough. At this point, he can investigate the failure source in a more specific way.

The system automatically chooses the questions according to the malfunction type (general malfunction and malfunction applied to the structural group), so that the range of elements can be reduced in the most effective way.

The user is asked to observe the crane performance or carry out small and fast tests on the crane subject to malfunction. The questions displayed allow the malfunction analysis from different points of view. This avoids the psychological inertia effect
and a consequent malfunction analysis based only on one's own technological background.

In this way, through a limited series of questions (usually 4-5), FIT enables the identification of a restricted range of elements on which investigation can be focused, to find the real malfunction cause.

6. Conclusions

The paper outlines a new after-sale service designed to identify quickly and easily the element that caused the failure of a Fassi crane through a series of guided questions about the behavior of the malfunctioning crane. The tool, called FIT (Fault Investigator Tool), allows Fassi a rapid and accurate diagnosis of the cause of failure.
The main novelty of the presented work lies in the method used to design the tool. By combining FMEA (Failure modes and effects analysis), TRIZ functional analysis and AFD, the authors were able to systematically search all the failures that may occur on the crane. The application of this failure identification procedure has revealed about 1500 failure modes of crane failure that were mapped and organized in order to be filtered by 150 questions. As the user answers the questions, the possible elements causing malfunction decrease to a point were only a few possible malfunctions have to be investigated.

The tool has been thoroughly tested on the field and has confirmed its potential for a rapid and accurate diagnosis of failures. Fassi Gru decided to use this tool for diagnosing faults in production, for ameliorating product design and will include FIT tool in its product service system distributing it to Fassi technical assistance and dealers.

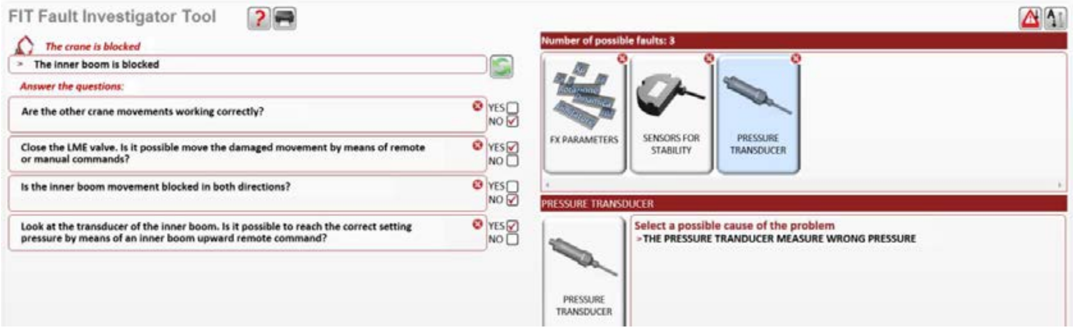

Fig. 9. FIT: user interface; questions (left), and remaining possible faults (right)

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