Matching TRIZ engineering parameters to human factors issues in manufacturing

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Abstract: - An overview of the development of the TRIZ problem solving approach is provided in the first part of this paper. Having emerged in Russia in 1946, the Theory of Inventive Problem Solving Technique (TRIZ) has been commonly used in the USA and Europe in the last few decades. TRIZ, as a method, has been used successfully to solve problems such as many of those typically arising during the process of product development, as reviewed in the second part of the paper. While the TRIZ method is also considered fit to address human factors problems in manufacturing, straightforward application would benefit from a resource gathering supporting knowledge and techniques. In the third part, analysis of previous work leads to suggest that new TRIZ method users might benefit from specific guidance in the interpretation of the engineering parameters in the contradiction matrix, considering human factors problems in manufacturing. A tentative correspondence is proposed in the fourth part between human factors issues in manufacturing and the engineering parameters in the matrix. The paper concludes emphasizing the need to further extract and categorize human factors and ergonomics principles and understand and analyze them under the light of the 40 inventive principles of TRIZ.

Key-Words: - Industrial engineering, Inventive principles, Contradiction, Resource for new users.

1 Introduction

Computerized tools with an inference engine, capable of suggesting solutions to problems, supporting decision makers, designers and engineers, are a well established approach. This is meant to expedite and streamline processes of creatively solving problems. As an example, consider the study by Dolšak [1] about the development of a double purpose system within the approach of intelligent design for X. The first part of the system is related to ergonomic and aesthetic design, while the second part is meant to provide advice and design strategies in product development using plastic materials. The system is based on an expert system approach, where an inference engine makes use of rules to provide design recommendations in an automated manner, contributing to the success and efficiency of the design process.

Many other attempts have been made to create tools, in many cases of a computerized nature, to try to bring some added efficiency to the process of solving human factors problems in manufacturing settings. As an example, albeit with a limited scope of application, given the wide ranging variety of issues that may be touched by the afore-mentioned kind of problems, the work of Wu and Chen [2] resulted in the development of a software tool that not only helps people to check their computer work settings by themselves, but also assists in improving or mitigating computer-related health risk factors while using a computer. The need for such software is derived from the fact that with the increase of computer usage, the complaints about musculoskeletal disorders have become more and more common in the workplace. In this example, the workers themselves are to use the software. In other situations, engineers are responsible for identifying and dealing with problems in the manufacturing domain, including health and safety related aspects.

Many SMEs (Small and Medium Enterprises) are not resourceful enough to benefit from the services of a human factors and ergonomics specialist. Even in larger companies, industrial engineers are often faced with ergonomic and health and safety challenges. The work reported in this paper aims at establishing the foundations to develop a resource to support engineering approaches to the solution of human factors problems, based on the contradictions matrix and on inventive principles included in the TRIZ method.

Since many of the human factors problems encountered in a manufacturing facility are found at the intersection between people, technology (equipment, machinery, computers) and work (tasks and activities that necessitate the interaction of people with technology), applying the inventive principles developed by Altshuller for the TRIZ methodology would appear to be reasonable. A question arises in terms of selecting the most appropriate principles given the contradictions that the problems at hand may represent. Prior to that there is another question to answer, concerning expressing the problem in terms compatible with using the contradiction matrix.

The use of TRIZ to solve human factors problems in manufacturing has been attempted and demonstrated by Akay et al. [3]. There are also specific examples developed in teaching the inventive principles of the TRIZ method that are set within human factors themes [4]. In an attempt to put together a resource of TRIZ related knowledge and techniques for application to human factors problems, previous work is reviewed. The result is evidence that while the skilled TRIZ problem solver will be able to apply TRIZ straightforwardly to this kind of problems, a novice user of the method might benefit from more specific material geared at human factors problems.

The most serious obstacle concerns the interpretation of the engineering parameters under the light of human factors problems in manufacturing. In this paper, a tentative and explorative translation is proposed between human factors issues in manufacturing and the engineering parameters in the contradiction matrix. This translation Table was put together based on the experiences of the author, in teaching ergonomics and human factors to designers and engineers and from contact with industrial engineering practice in manufacturing plants.

The variables in TRIZ are very much tied up with engineering problems, although TRIZ is powerful enough to be a universal problem solving method. Because this power may at times seem too great and difficult to use, this has led to the identification of a smaller set of principles, set forth in the five idea-provoking tools [4] depicted in Table 1.

Table 1: Idea-provoking tools [4].

Tool	Description
Unification	Solve a problem by assigning a new use to an existing component.
Multiplication	Solve a problem by introducing a slightly modified copy of an existing object into the current system.
Division	Solve a problem by dividing an object and reorganizing it parts.
Breaking Symmetry	Solve a problem by turning a symmetrical situation into an asymmetrical one.
Object Removal	Solve a problem by removing an object from the system and assigning its action to another existing object.

While the engineering principles in the contradiction matrix may be too specific at times, and the inventive principles overwhelmingly complex, the five idea-provoking tools shown above may be too generic. A trade-off needs to be established between the power of the TRIZ method, the specificity of the contradictions matrix and the selection of inventive principles. This paper is aimed at giving a contribution to streamline the effective application of the TRIZ problem solving method to a subset of problems with a human factors theme.

In what follows, an overview of the development of the TRIZ problem solving approach is offered. This is followed by a section on the TRIZ method, as well as a set of examples and previous work that was developed. The examples include cases of straightforward application of the TRIZ method, as well as adaptations to the method in order to deploy it in different problem domains. A tentative correspondence, based on analysis of the examples pertaining to the manufacturing section, is established between engineering and human factors concepts. The fifth section of the paper discusses the needs identified in applying TRIZ to human factors problems in manufacturing, and proposes a generalized correspondence of engineering parameters and human factors concepts, which consists of the main result of this study. The paper concludes with an outline of the challenges and the envisaged concurrent approach for the full application of TRIZ to human factors problems.

2 Overview of the development of the TRIZ problem solving approach

The short overview of the creation of TRIZ provided in this section is based on [6]. Genrich S. Altshuller, also known as Henry Altshuller and the man who developed the technology patent based TRIZ approach, was born in the former Soviet Union in 1926. His first invention, intended to support the activity of scuba diving, was made when he was only 14 years old. This hobby of his was one of the main factors leading him to pursue a career as a mechanical engineer. Serving in the Soviet Navy as a patent expert during the 1940s, his formal job consisted in helping inventors apply for patents. He found, however, that he was often asked to assist in solving inventive problems as well. His curiosity about problem solving then led him to start devising standard methods. He had found that the psychological tools available by that time did not meet the rigors of inventing in the 20th century. Altshuller felt a theory of invention should satisfy the following minimum conditions: it should be a systematic, step-by-step procedure; it should consist of a guide through a broad solution space to direct to the ideal solution; it ought to be repeatable and reliable and not dependent on psychological tools; it ought to be able to access the body of inventive knowledge; it should be able to add to the existing body of inventive knowledge; and it should be familiar enough to inventors by following the general approach to problem solving.

Altshuller screened thousands of patents looking for inventive problems and how they were solved. Only a small proportion of the patents had somewhat inventive solutions; while the rest were straight forward improvements. Thus, Altshuller then more clearly defined an inventive problem as one in which the solution causes another problem to appear, such as in increasing the strength of a metal plate, and in such, causing it's mass to increase.

Usually, inventors must resort to a trade-off and compromise between the features of the engineering problem and thus do not necessarily achieve an ideal solution. In his study of patents, Altshuller found that many of the patents described a solution that eliminated or resolved the contradiction between parameters and required no trade-off, meaning that an ideal solution could be found and deployed.

Altshuller then categorized these patents in a novel way. Instead of classifying them by industry category, such as automotive, aerospace, and so forth, he uncovered the problem solving process by removing the subject matter. He found that, often, the same problems had been solved over and over again using only one of forty fundamental inventive principles. If only later inventors had knowledge of the work of earlier ones, solutions could have been discovered more quickly and efficiently.

In the 1960s and 1970s, he categorized the engineering solutions into five levels, summarily explained in what follows.

Level 1 - Routine design problems solved by well known methods within the engineering or industry specialty. No invention was needed. About 32% of the solutions fell into this level.

Level 2 - Minor improvements to an existing system, using methods known within the industry. Usually this type of solution involved some compromise. About 45% of the solutions fell into this level.

Level 3 - Fundamental improvement to an existing system, by methods known outside the industry. This type of solution meant that contradictions were resolved. About 18% of the solutions fell into this category.

Level 4 - A new solution generation that uses a new principle to perform the primary functions of the system at hand. This solution type was typically more often found in science than in technology problems. About 4% of the solutions fell into this category.

Level 5 - This type of solution consisted of a rare scientific discovery or pioneering invention of essentially a new system. About 1% of the solutions fell into this category.

Altshuller also noted that within each succeeding level, the source of the solution required a broader knowledge set and that more solutions had to be considered before an ideal solution could be found. What Altshuller tabulated then was that over 90% of the problems engineers faced had been solved somewhere before by someone else. If engineers could follow a path to an ideal solution, starting with the lowest level, their personal knowledge and experience, and working their way to higher levels, most of the solutions could be derived from knowledge already present in the company, industry, or in another industry.

Consider the following example. A problem in the use of artificial diamonds for tool manufacturing is the existence of invisible fractures in the artificial diamonds [7]. Traditional diamond cutting methods often resulted in new fractures which did not show up until the diamond was in use. What was needed there was a way to split the diamond crystals along their natural fractures without causing additional damage. A method used in food canning to split green peppers and remove the seeds was then put to use. In this process, peppers are placed in a hermetic chamber in which air pressure is increased to 8 atmospheres. The peppers shrink and fracture at the stem. Then the pressure is rapidly dropped causing the peppers to burst at the weakest point and the seed pod to be ejected. A similar technique applied to diamond cutting resulted in the crystals splitting along their natural fracture lines with no additional damage.

Altshuller distilled the problems, contradictions, and solutions in these patents he scrutinized into a theory of inventive problem solving which he named TRIZ.

3 The TRIZ method

TRIZ, which is an abbreviation for '*Theoria Resheneyva Isobretatelskehuh Zadach*' in Russian, is translated as the 'Theory of Inventive Problem Solving'. Following its initial use by Altshuller, especially as a useful technique for patent applications, TRIZ gained wider application and has become a well disseminated problem solving tool [6].

Having realized that the development of technological systems followed a foreseeable path that intersected with all fields of science, Altshuller determined that the problem solving approaches deployed may be repeatable and predictable. This approach is the main idea from where the TRIZ method arises. Many studies have described the philosophy of the TRIZ method with a mathematical 'operator' expression. If a mathematical problem has a general solution, then a solution to a specific problem could be easily solved just by using the specific values in the solution and solving the problem numerically. From this point of view, TRIZ has formed the general solutions to the problems and allowed people to find easy and quick solutions to their problems by providing them with some principles [8].

In the TRIZ problem solving approach, every factor that affects a system is a parameter [7]. There is a dependent relationship between the parameters of the system. While some parameters have positive effects on other ones, some of them have negative effects. The parameters that have negative effects on other ones are said to be in contradiction. TRIZ is based on modifying the system to increase ideality by using a 39 times 39 contradiction matrix of engineering parameters. In the matrix, improving and worsening parameters are inserted and the matrix proposes some principles among 40 'Inventive Principles'. After interpreting these principles, a solution may be found by using the TRIZ method. The purpose is hence to improve a parameter without worsening the other parameter, and thus, reducing the contradiction.

Naturally, the success of TRIZ has attracted people and many papers about this method are to be found in literature. TRIZ has been dealt with in axiomatic design [9]. A frame of reference for using TRIZ in the design process was formulated [10]. The problem of environmental protection in the process of product development was dealt in the frame of TRIZ [11]. Cavallucci et al. [12] mentioned the use of TRIZ in order to include creativity in the design process. The joint use of QFD and TRIZ has been discussed in product development [13]. Vincent and Mann [14] did a modification to TRIZ to solve a problem in biology. The use of TRIZ in designing was discussed with different examples [15]. TRIZ and the Theory of Constraints (TOC) were evaluated together in the process of improving a manufacturing system [16]. TRIZ was used in engineering designs [17]. 'Design for Manufacture and Assembly' (DFMA) and TRIZ methods were used together to reduce part counts in order to simplify a product structure [18]. The tools of product design were successfully used with TRIZ in the process of replacing metal parts with plastic ones [19]. The vibration, noise and energy loss problems faced in hydraulic disc brake systems were solved by using TRIZ [20]. The TRIZ method was employed to remove the problems that arise due to high pressure and temperature in the plastic materials of valve systems [21]. TRIZ is also used in thousands of other areas of research and has become indispensable for large companies such as Ford Motor, Motorola, Boeing and NASA [22].

4 Examples and previous work

This section provides some examples of the use of TRIZ tools to solve problems with some displacement in relation to the initial application area of the approach, given in the first subsection. It also reviews two cases of previous work on the use of the TRIZ method to solve human factors issues in manufacturing, in the second subsection. Finally, in the last subsection, a proposal is tentatively considered concerning the correspondences that must be done in order to make use of the TRIZ inventive principles to deal with specific human factors problems.

4.1 Examples of the use of the TRIZ tool set in settings different from the one it was originally intended for

Over the recent past, TRIZ has been put to service in several domains, with a slight displacement of its original purpose as a tool set. This subsection provides several examples of this kind.

The Eco-Design Tool is CAD software intended for problem solving, aimed at solving conflicts in sustainable product development, and supporting the achievement of eco-innovative conceptions [23]. The software, which consolidates TRIZ and other related techniques, assists design engineers in making strategic decisions for their design projects, recommends them practical TRIZ engineering parameters and feasibility principles, and inspires them through the interpretation of 40 inventive principles and cases.

Another study deployed the TRIZ creativity intensification approach to the development of chemical process safety [24]. The study developed a modified version of TRIZ to improve safety in chemical process design. This method is based on the theory of TRIZ, for retrofit design of chemical processes considering safety. The authors considered that the original TRIZ tool set was difficult to access for chemical process safety, due to the inapplicability and ambiguity of the terminology in the classification of these parameters. It was hence necessary to pursue the development of a modified TRIZ version for its deployment within the chemical process safety domain. This study reorganized the thirty-nine engineering parameters of the TRIZ contradiction matrix into six categories: mechanic, operator, process setup, design, natural hazard and material. It also presents two case studies that showcase the application of the modified TRIZ version to a jacketed reactor and a polyethylene reactor, which according to the authors, offers a compatible method to solve problems in chemical process safety. In the first case, the contradiction was summarized as expressed in the following (numbers in parentheses indicate the engineering parameter number in the contradiction matrix).

Contradiction – improving engineering parameter - control the jacketed reactor's temperature properly (17, temperature); worsening engineering parameter - additional equipment which controls the temperature of jacketed reactor increases the complexity of this equipment (37, complexity of control). This contradiction was solved by considering inventive principles 3 (Local quality) and 35 (Parameter changes), resulting in inserting additional cooling water into the cooling jacket.

In the second case reported [24], the two contradictions involved may be summarized as stated in the following paragraphs.

Contradiction 1 – improving engineering parameter - reduce the leakage danger of combustibles such as hexane (23, loss of substance); worsening engineering parameter - additional equipment decreases the efficiency of the process (33, ease of operation). Inventive principle 28, replacing mechanical system, which is suggested in the contradiction matrix for the conflict between engineering parameters 23 and 33, was followed. This resulted in changing the mechanical operation valve into an electrical valve, thus solving the problem.

Contradiction 2 – improving engineering parameter - reduce the igniter (30, object-affected harmful); worsening engineering parameter - additional equipment increases the complexity of the process (36, complexity of device). For this contradiction (between engineering parameters 30 and 36), inventive principle 40, composite materials, was selected. Its application to the problem resulted in changing the surface of pipes and equipment into an insulating material, therefore, solving the problem.

Interestingly, studies dealing with contradictions between parameters in manufacturing processes, do not always take the TRIZ method into account, but may solve problems in a way that would be recommended as a result of the use of a TRIZ tool set, with efficiency gains. Such is the case of the study [25] summarily described in what follows. There are many robots designed for automatic production in the stamping sector. However, none has satisfied the needs to abide to the efficiency standards of the industry at an affordable cost. The study reports on the development of a low cost robot which solves the problem in an efficient way. One of the key ideas of the robot is the utilization of two fixed arms working in parallel, with time delay, but that are part of the same process. This separation of work in two manipulators helps the robot work twice as fast to improve the printing and stamping of the plastic pieces. The economic analysis of the system reveals clear advantages over the manual system. Hence, in this case, separation was the inventive principle used to find a solution. This is part of the TRIZ tool set, despite not being deployed in the study. TRIZ methods might have led, with added speed, to a similar or improved solution.

4.2 Previous work on the use of the TRIZ method for human factors issues in manufacturing

Two examples of the use of the TRIZ method to solve human factors problems in manufacturing were reported by Akay et al. [3] and are summarized in the following Tables (2 and 3). The first pertains to detection of defects under inadequate illumination conditions (Fig. 1). The second one concerns fatigue and idle time and efficiency concerns (Fig. 2). The method proposed by these authors respects the following steps, illustrating a typical problem solving approach supported by TRIZ: define the problem; determine the basic solution; determine the contradictions against the basic solution; determine the inventive principles via TRIZ; interpret the principles; apply the principles to the problem.

Figure 1: Illumination in defects detection task (artwork by Andreia Campos).

Table 2: Example of the use of the TRIZ method to solve an illumination problem in manufacturing (abridged from [3]).

Problem	Operators cannot detect defects due to insufficient illumination.
Basic solution	Increasing illumination by using additional lamps.
Contradictions (numbers indicate engineering parameters from the matrix)	Increased energy consumption due to increased light intensity (18–22). Increased energy consumption while increasing measurement accuracy (28–22). Increased energy consumption while increasing production accuracy (29–22).
Inventive principles extracted from the contradictions matrix that apply to the case at hand	1 Segmentation (actually used) 2 Extraction (actually used) 6 Universality 13 Inversion (actually used) 16 Partial or overdone action 19 Periodic action (actually used) 22 Convert harm into benefit (actually used) 26 Copying 27 Inexpensive, durable one 32 Changing the colour (actually used)
Solutions to the problem	Workshop layout is rearranged according to the need for light intensity for the operations in which visual inspections are clustered. Needs for light intensity and current situations are compared and unnecessary illumination tools and saved energy are allocated to the parts that need more light. Manufacturing and inspecting operations are separated and light intensity is increased for inspection while it is being decreased for other operations. Motivation of the operators in detecting the defects is increased by applying a penalty system. Indicators that identify rust and similar defects are determined, and by changing the colours it became easy to see the defects.

Figure 2: Fatigue inducing repetitive movements in manufacturing (artwork by Andreia Campos).

Table 3: Example of the use of the TRIZ method to solve a fatigue problem in manufacturing (abridged from [3]).

Problem	Fatigue of the operators.
Basic solution	Reducing fatigue without increasing idle time and decreasing efficiency.
Contradictions (numbers indicate engineering parameters from the matrix)	Increasing time losses while decreasing fatigue (14–25). Decreased efficiency while decreasing fatigue (14–39). Increased fatigue due to decreased time losses (25–14). Increased fatigue due to increased efficiency (39–14).
Inventive principles extracted from the contradictions matrix that apply to the case at hand	3 Local quality (actually used) 10 Prior action 14 Spheroidality (actually used) 18 Mechanical vibration 28 Replacement of a mechanical system (actually used) 29 Pneumatic or hydraulic construction 35 Transformation of the physical and chemical states of an object
Solutions to the problem	Clothing and shoes of the operators should be redesigned so that fatigue is reduced. Working hours should be rescheduled and the lengths of the rest periods should be decreased while the number of rest periods is increased. Layout of the workbenches should be scrutinized and spherical or curved layouts should be used instead of linear layouts, e.g. a ‘U-shaped’ layout can be used. Making improvements in the system to make loading–unloading operations or to speed up the failure detection process will decrease fatigue with reasonable costs.

Table 4: Examples of the use of inventive principles to solve selected human factors problems based on selected Tate and Domb's [5] descriptions of 40 inventive principles.

Problem / solution	Noise / Locate a noisy compressor outside the building where compressed air is used	Poor functionality / Adjustable steering wheel (or seat, or back support, or mirror position…)	Discomfort / Comfortable shoe sole inserts filled with gel
Inventive principle No.	2	15	29
Type of approach	Taking out	Dynamics	Pneumatics and hydraulics
Sub-type of approach	Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.	Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.	Use gas and liquid parts of an object instead of solid parts (e.g. inflatable, filled with liquids, air cushion, hydrostatic, hydro-reactive).
Contradiction parameters	Noise (31-Object-generated harmful factors) x Comfort (39-Productivity) and Health (27-Reliability)	Allow characteristics to change (13-Stability of the object's composition or 12 – shape – opposite of 35-adaptability or versatility) x operating conditions optimization (33-ease of operation)	Comfort (33-ease of operation, 39-productivity, 35-adaptability or versatility opposite of 31 - object-generated harmful factors or 11 - stress – pressure) vs. object rigidity (13 - stability of the object's composition or 12 - shape)
Cells in 39x39 matrix	31-27; 27-31	33-12; 12-33	33-12

4.3 A tentative correspondence between TRIZ parameters and human factors aspects

Analysis of previous work suggests that new TRIZ method users might benefit from specific guidance, since some of the steps taken involve a correspondence between the engineering parameters and human factors issues. There is room to provide more support in the interpretation of the engineering parameters in the contradiction matrix when considering human factors problems in manufacturing.

The following example, depicted on Table 4, is an elaboration based on a selection of descriptions of 40 inventive principles [5]. The examples selected illustrate the use of inventive principles to deal with specific human factors problems. The contradiction engineering parameters were tentatively sought and several possible contradictions could represent the problem in each case. These are also shown in Table 4. The contradiction pairs were then input into the contradictions matrix, and the pairs that led to the recommendation of the inventive principle considered are shown in the last row of Table 4.

This attempt at finding contradiction pairs that point (in the contradictions matrix) to the inventive principles the problem illustrates, necessitated a conversion from human factors problems to engineering parameters. Several correspondences were essayed, highlighted in Table 5.

Table 5: Essayed conversion from selected human factors concepts to engineering parameters.

Human factors concepts	Engineering parameters (TRIZ contradictions matrix)
Comfort	27-Reliability 33-Ease of operation 35-Adaptability or versatility 39-Productivity
Ease of use	33 - Ease of operation
Fatigue	14 - Strength (opposite)
Noise	31 - Object-generated harmful factors
Stress	11 - Stress - Pressure

5 Challenges in applying TRIZ to human factors in manufacturing

Akay et al.'s [3] proposed use of the TRIZ method to human factors problems (shown in Tables 2 and 3) may be enhanced by suggesting some ways of interpreting the 39 engineering parameters in terms of human factors terms. The issue of fatigue is dealt with as strength, No. 14 in the contradictions matrix, by those authors. Based on this consideration and on examples from Tate and Domb [5], a partial tentative correspondence was essayed (Table 5) between human factors concepts and specific TRIZ parameters. Although the variables in TRIZ are very much tied up with engineering problems (while TRIZ is powerful enough to be a universal problem solving method), what the analysis of Tate and Domb's [5] examples suggests is that some additional support is needed to ease the application of the TRIZ method to human factors problems. A contribution is essayed in the following subsection, taking the 39 engineering parameters and searching for corresponding human factors concepts or aspects.

5.1 Proposed generalized correspondence

In what follows, an exploration of the 39 engineering parameters is made, seeking corresponding human factors and ergonomics concepts and issues. The goal is to provide a supportive tool for more easily leading with human factors problems in manufacturing, while adopting a TRIZ based problem solving method. Table 6 presents the tentative correspondence, which builds on the authors' assessment of the two domains of human factors and engineering.

Table 6: Exploration of the 39 engineering parameters of the TRIZ contradiction matrix, seeking corresponding human factors concepts.

Engineering parameter (from TRIZ's contradictions matrix)	**Corresponding human factors and ergonomics concepts**
1-Weight of moving object	Weight a person supports while carrying out activity.
2-Weight of stationary object	
3-Length of moving object	Dimensions of objects interact with anthropometric restrictions such as reach and free space, and also with egress and ingress requirements.
4-Length of stationary object	
5-Area of moving object	
6-Area of stationary object	
7-Volume of moving object	
8-Volume of stationary object	
9-Speed	Speed of movement of the person.
10-Force (Intensity)	Force applied by the person.
11-Stress or pressure	The concepts of stress and pressure apply to contact of the person with physical interfaces.
12-Shape	Anatomical contours in relation to the person.
13-Stability of the object's composition	Rigidity of layout of objects and tools used by the person.
14-Strength	Strength needed to perform tasks (related to fatigue).
15-Duration of action of moving object	Time duration and frequency of the person's action with interacting objects.
16-Duration of action by stationary object	
17 - Temperature	Factors of the thermal environment.
18 - Illumination intensity	Factors determining visual accommodation.
19 - Use of energy by moving object	Energy consumption incurred by the person in performing work tasks.
20 - Use of energy by stationary object	
21 - Power	Energy consumption rate needed by the person to perform the activity.
22 - Loss of Energy	Heat loss and gain of the person in action, fatigue.
23 - Loss of substance	
24 - Loss of Information	Cognitive issues may give place to an information overload instance.
25 - Loss of Time	Pauses and rest periods (recovery from exertion).
26 - Quantity of substance/the matter	
27 - Reliability	Ability of the person to perform a task maintaining a set standard.
28 - Measurement accuracy	
29 - Manufacturing precision	Time duration and frequency of the person's action with interacting objects.
30 - Object-affected harmful factors	Factors pertaining to the interacting environment, tools and objects that are harmful to the person.
31 - Object-generated harmful factors	
32 - Ease of manufacture	Ease of use, or usability of the technical object or system in relation to the person. The concept of comfort may also be implied.
33 - Ease of operation	
34 - Ease of repair	
35 - Adaptability or versatility	Human requirements on adaptability.
36 - Device complexity	Complexity in cognitive terms.
37 - Difficulty of detecting and measuring	
38 - Extent of automation	Nature of tasks performed by the person (supervisory, execution, manual or other).
39 - Productivity	Efficiency of the human-technology-work system.

While many engineering parameters have a repercussion in human factors concepts, it is also true that some aspects of human factors are not illustrated in Table 6 (psychosocial aspects, for instance). Others are considered generally, under a big category (harmful effects, for instance). Hence a concurrent approach needs to be pursued in supporting the consideration of concepts that do not find correspondence in the TRIZ engineering parameters, in order to support the development of the solution. Such a concurrent approach is depicted in Figure 3.

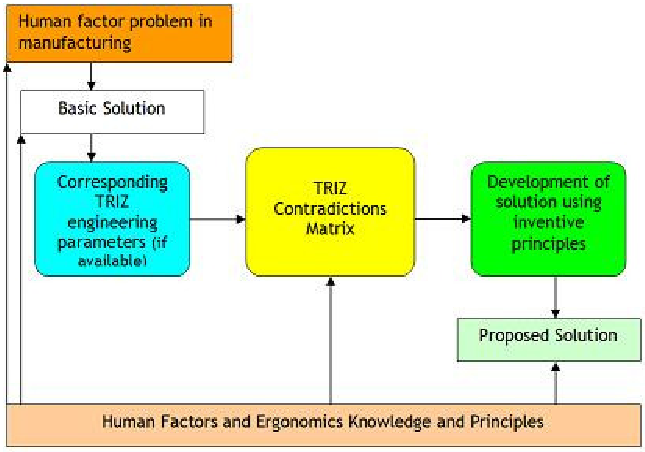

Figure 3: Concurrent approach to solving human factors problems in manufacturing given the incomplete correspondence between human factors concepts and TRIZ engineering parameters.

Interpretation (or weighing) of the concepts in the second column of Table 6 requires further information that springs from the principles, knowledge and recommendations of Human factors and Ergonomics. In most cases, the concept may represent a harmful effect on the person, depending on specific characteristics of the task, the individual, the duration of the effort, and so on.

6 Conclusion

A major challenge made evident from the previous discussions is the need to extract and categorize human factors and ergonomics principles and understand and analyze them under the light of the 40 inventive principles of TRIZ, and the 5 idea tool kit [4]. This requires establishing a knowledge base that will concentrate information on human factors issues in manufacturing in a manner compatible with the TRIZ problem solving method.

Another challenge in easing application of the TRIZ, or of a TRIZ compatible, approach to this kind of problems is seeking the extension of the TRIZ methodology to areas in Human factors and Ergonomics (HFE) that do not find equivalent correspondence in the engineering parameters. The activities envisaged in such extension tasks would encompass:

a. Exploring the HFE field to extract relevant concepts that might stand in conflict to engineering and human factors concepts in specific manufacturing problems.

b. Eliciting the principles of Human factors and Ergonomics action and proceed to understand and decompose them under the light of the inventive principles, if possible.

c. Developing a resource that outlines the contradictions between engineering and human factors parameters, on the basis of the contradictions matrix and an added appendix if necessary.

d. Conducting case studies to validate, and, or improve the resource outlined in (3).

e. Devising an expert system armed with the capability to weigh and estimate the effects on the individual of specific values assumed by the parameters considered (taking context specific information into account).

The envisaged process of solving human factors issues in manufacturing would then take the form of the process depicted in Figure 4.

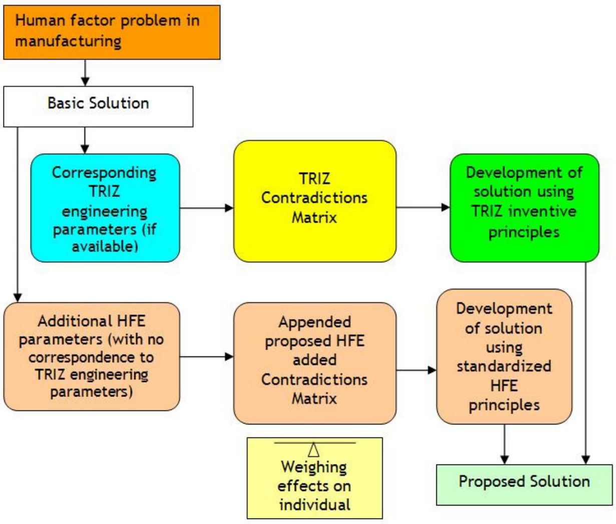

Figure 4: Envisaged concurrent approach to solving human factors problems in manufacturing based on TRIZ, and once the challenges outlined in this section have been overcome.

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