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# Design Support for Maintenance Tasks using TRIZ

Tom Vaneker*, Tijmen van Diepen

*University of Twente, Drienelerlolaan 5, 7522 NB, Enschede, The Netherlands*

* Corresponding author. Tel.: +31 53 4892472; *E-mail address:* t.vaneker@utwente.nl

**Abstract**

Design for Maintenance is a method to optimize maintenance activities during the design process. To help maintenance engineers, the chair Maintenance Engineering at the University of Twente has set up a list of 37 guidelines. However, these guidelines only state the goal that should be achieved, but do not define the actions that should be taken to solve maintenance-related problems during the design phase. TRIZ is a product and process innovation method that uses various tools that propose paths to possible innovations and solutions. As such, TRIZ promises it could be a useful addition to the existing set of 37 maintenance guidelines. In this research the compatibility of TRIZ and maintenance guidelines is explored using a 3 stage research plan. Firstly, applicable guidelines are linked to TRIZ methods. In a second step these links are grouped and generalized so not every maintenance guideline also needs a unique TRIZ strategy. Finally a roadmap is presented that helps during Design for Maintenance activities in solving maintenance problems with the support of TRIZ tools.


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*Keywords:* Maintenance,: TRIZ: Design for Maintenance

## 1. Introduction

As also stated in [1] an increasing number of manufacturing companies shift from a product oriented development strategy to a service oriented one. In this service based approach value is considered to be derived from supporting and enhancing the customer's use of products. This service orientation is defined as

- the activities relating to the maintenance and repair of products;
- the performance or support of certain activities related to the transformation process of technical systems;
- or as the performance or support of certain responsibilities related to the customer activities.

In [2] it is stated that maintenance is perhaps the most expensive of all human–machine system activities. This is because of the increasing need to perform maintenance activities and the high and the ever increasing cost of human labor involved. For example Aircraft maintenance costs in the United States has been estimated to amount to approximately 35% of life cycle costs of military systems. Also in the 1970's the U.S. Department of Defense allocated one quarter of its budget to maintenance costs.

From these examples it is evident that in the service oriented product development strategies the reduction of the costs (time, money, loss of product use etc.) of maintenance activities is of great importance. The chair Maintenance Engineering at the University of Twente established guidelines for maintenance engineers that can be used to decrease the cost of maintenance activities during the design phase of a new system [3]. However, these guidelines indicate were the problems will arise but do not offer any indication on how they may be applied to solve maintenance problems.

TRIZ was identified as a possible useful addition to support the maintenance engineers to come to innovative solutions for their problems. To prove this assumption a 3 stage research plan was set up.


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- The first stage (chapter 3) investigates if and how TRIZ can benefit from maintenance guidelines. This is done by linking TRIZ tools to a subset of eight different guidelines.
- In the second stage (chapter 4) these links are further investigated. The purpose of this is to find patterns in order to proof that TRIZ could possibly be used for all guidelines, and not just for the eight selected.
- To further prove the usability of the TRIZ, different maintenance problems from practice are solved using the new links between the guidelines and TRIZ. In the final stage a roadmap is defined (chapter 6) that explains how maintenance problems can be solved by using these new links.

## 2. Design for maintenance

### *2.1. Design for maintenance strategies*

Design for Maintenance aims to influence maintenance activities during the design phase of new systems. There are three categories of Design for Maintenance; maintainability, reliability, and supportability [3].

- Design for maintainability is designing equipment so it can be repaired quick and easy.
- Reliability focuses on reducing the failure rate of the equipment.
- Taking supportability into account means that the equipment can be supported fast and easy.

It is implicit that during product design, maintenance activities should be taken into account. For example [4] proposes a set of design axioms to be considered during the designs stage: simplicity, part features, operating environment, part identification, and assembly/disassembly principles. In [5] a game theoretic approach is used to improve the product design for maintainability. The product designer and maintenance engineer are the participants in the game and a combined product optimization function is defined. The outcome of the game is a compromise between the ideal product configurations of the product designer and the maintenance engineer. Many more examples can be found in literature. For example [2] lists an extensive overview of these design approaches for maintenance.

To aid maintenance engineers in reducing the number of maintenance activities, to make them easier to execute, or to decrease the support time required, the chair Maintenance Engineering at the University of Twente established 37 guidelines for design for maintenance [3] that are based on practical experience (See appendix A). The guidelines are proven to be useful to analyze a system or to categorize a maintenance problem. This helps the maintenance engineers because it provides a direction in which to look for solution(s). However, as is the case with the other design for maintenance approaches; the guidelines tell the designer what the possible problem looks like but does not provide an indication how the problem should be solved.

### *2.2. Design for maintenance and TRIZ*

The purpose of this paper is to research the possibilities to link structured design for maintenance approaches to systematic product innovation methods (in this case TRIZ). Linking TRIZ to maintenance activities is not new. [6] And [7] are exemplary case studies of using TRIZ to solve well defined but unique maintenance problems. [8] Describes a more generic approach for maintenance support. Questionnaires, cause and effects diagrams and QfD schemes are used to analyze the current system and to identify the most promising maintenance strategy. It is proposed to execute this strategy by applying the contradiction matrix from TRIZ.

## 3. Linking the 37 maintenance guidelines to TRZ

### *3.1. Exclusion of guidelines*

Before the suitability of linking TRIZ to the maintenance guidelines is investigated, the guidelines themselves were inspected. The guidelines not taken into account and the reasons therefore are listed below.

- (#13) Position the maintenance points close to each other. The proximity of maintenance points is a requirement that is modelled during the factory and facility planning, and deals with different types of problems.
- (#17) Design for under stressed use: For a system to handle the stresses while delivering the desired maximum output. The system should be required to handle stresses that exceed this maximum output. This guideline is easily achieved by changing the maximum requirement.
- (#29) Save useful life time data: To predict when maintenance is needed in the future, data of the past can be used. Therefore all the useful data should just be stored.
- (#30) Avoid that secondary tasks consume a lot of time: This guideline involves structuring tools and properly displaying data, and no problem solving.
- (#34) Build monitoring equipment into the system: This guideline already provides a solutions and does not need further explanations how to execute.
- (#36) Provide understandable maintenance instructions: Setting up maintenance instructions involve structured information display. It does not involve finding new solutions. It is however possible to make maintenance instructions more understandable, by making the systems easier to handle. This is however discussed in another guideline (#4).

### *3.2. Linking of guidelines to TRIZ*

After the original list was reduced to 31 maintenance principles, the remaining principles were linked to existing TRIZ problem solving and innovation approaches by an investigator with a working knowledge of both TRIZ and Design for Maintenance. The full list of links between the maintenance principles and TRIZ methods can be found in appendix B. For 8 of these principles (#2, #6, #9, #14, #15, #21, #27, and #31) links were defined and explained further in this paragraph by first explaining the guideline and then method used for linking it to a TRIZ tool.

*#2 Use standard, universally applicable components.* Standard, universally applicable components are widely understood by technicians. Maintainability becomes therefore easier when these types of components are used. For example, the standard bolt used in a company for all pieces of equipment are M3 size bolts.

It is not always possible to change a component into a standard, universally applicable component. To solve this problem, Root Conflict Analysis could be used to find the essential conflict why this is not possible. When the main conflict is determined, Inventive Principles can be used to find solutions. The result is that the system is changed in such way, that a standard, universally applicable components can be used.

*#6 Design equipment in such a way that it can only be maintained in the right way*. When maintenance can be executed in only one correct way, mistakes are prevented. An example of this is using an asymmetrical gear. This is a gear with a notch at one side. The notch prevents mounting the gear incorrectly. It is complex to design a system that allows maintenance to be performed in only the right way. It requires wrongful ways to be eliminated and the right way to become obvious. So TRIZ can aid in determining what the right way is and how the system can be redesigned so that only this right way is possible. To do this, the guideline is changed from “the right way”, to “not the wrong way”. Using Problem Perception Mapping the different views on the cause of the “wrong way” are identified. This is done by the members of the design team and the maintenance crew. Both stakeholders in solving the problem. By mapping all the causes, a main problem is detected. This can be translated to the main conflict using Root Cause Analysis. And finally solved using the Inventive Principles.

# 9 *Design modular*. When a system is divided into several removable components, the system is easier to maintain. A broken module (or a module that contains a broken part) can easily be removed from the total system and be replaced with a new module that is in stock. An example are the tires on a truck. The different parts (wheel, tire, inner tube, etc.) can be regarded as one module. These are removed together, which speeds maintenance activities. And because the parts are interchangeable with a lot of different trucks, maintenance is easier to execute and stock is smaller. The first difficulty of modular design is to determine what components to include in one module. Small modules increase the maintenance time, while large modules are expensive in stock and can be difficult to handle. Secondly, it is difficult to determine the interfaces with other modules, the system, and the super-system. The interfaces should not reduce the total reliability, but allow for swift maintenance. To determine the right size and to create proper interfaces, all subsystems, super-systems (maintenance tools) and their interfaces should be mapped using Functional Analysis. This model allows maintenance engineers to analyze what to include and exclude from a module. As an example; the module of a tyre on a truck includes the bolts, but not the axle. By mapping the systems and their interfaces, it becomes apparent that the axle has a lot of interfaces and has to perform a lot of functions. This makes it difficult to remove the module tire, including the axle.

#14 *Design-out moving parts.* The reliability of a system is improved when unnecessary movement is avoided. Since movement often leads to friction, leading to components to wear down over time. An example of designing-out moving parts is the transition from hard disk drives to solid state drives. It may not always be possible to design-out the moving part. To solve this problem, Root Conflict Analysis and Inventive Principles are used. Using Root Conflict Analysis the engineer defines the main conflict that arises when the moving part is eliminated. Subsequently the maintenance engineer can use Inventive Principles to solve the main conflict and eliminate the moving part. Considering the transition from HDD to SSD. The main conflict of removing the rotating disk was determined. “A disk should rotate to rapidly find and store information, but to improve the reliability the disk should be stationary”. Finally a solution needs to be found that solves this contradiction without compromises.

#15 *Avoid unnecessary components.* By eliminating unnecessary components the number of components that can break down is decreased. Additionally by combining two or more components with a different function into one component, the complexity of the system can be reduced. Both aspects increase the reliability of the total system. An example of this is the transition from a mouse with a ball to an optical mouse. The optical mouse, containing less components, has a lifespan that exceeds the ball version. It is hard to determine if a component is unnecessary, and whether or not two components can be combined. To determine this, all the positive interactions of the components are mapped using Function Analysis. These interactions are prioritized and based on this prioritization the unnecessary components are trimmed. Example; the mechanical ball mouse contains a sensor that registers the movement of the ball, and by this the movement of the mouse. Combining the ball and the sensor, the mouse registers it movement directly with an optical sensor. Hereby the optical mouse was invented.

#21 *Do not use coated, painted or plated components.* Components that are coated, painted, and plated often need more maintenance to keep them in a good condition. To reduce maintenance, it is preferred not to use a coating but to find another solution to protect the component. An example of this guideline is the usage of stainless steel, instead of using metal with a coating against corrosion. For this guideline coatings, paint or plates can be either be trimmed, using the same method as the guidelines before (Function Analysis and Function Idealization). Or the functions of the component can be split. This is controversial with the previous guideline, since more parts can also increase maintenance efforts and costs. However, by splitting the functions, different functions can be executed by different components. This reduces complexity and makes the total system easier to maintain. Splitting can be done by firstly using Function Analysis, to identify the subsystems and the functions they deliver. Using this model the components that should be split can be analyzed. After splitting, the Catalogues of Effects can be used to find an effect that can deliver the new desired functions. As an same example; a single component has two functions. Protecting the system from debris, and supporting electrical wires on the inside of the system. By splitting the functions, the protecting component can be made of stainless steel. While plastic supports can support the wires. So when either one breaks down, they can be replaced separately instead of replacing both.

#27 *Avoid that expensive spare parts need to be held in stock.* This guidelines helps to reduce the inventory costs by designing systems that have cheap spare parts. An example is the carbon brushes in an electrical motor. The brushes are easy to replace when broken, while replacing the rotor would be much more expensive. So by making the brushes weaker, they will wear down instead of the expensive rotor. Less expensive parts are often singular parts. So modules are more expensive, but by using modules the maintenance time is decreased. The result is a contradiction, which can be formulated as: “A spare part should be small to reduce cost, but should be large to reduce maintenance”. For every different problem, the contradiction should be reformulated so it corresponds to the situation. Using Inventive Principles the stated contradiction can subsequently be solved. In the example the contradiction would be formulated as: “Carbon brushes prevent the expensive rotor from wearing down, but by using carbon brushes the reliability of the total system is reduced.”

#31 *Design for the use of standard tools.* A system should be designed so that a technician can maintain the system using standard tools. This reduces costs on unique and special tools, and reduces maintenance time since technicians are familiar with standard tools. An example of this is only using bolts that fulfil to the ISO standards. It is not always possible to design a system so it can be maintained using only standard tools. To get a clear overview of what prevents the use of a standard tool, the system (including the non-standard component) should be modelled using Function Analysis. This allows a good analysis of the interactions. The next step is to replace the non-standard component with a standard component. The interactions that

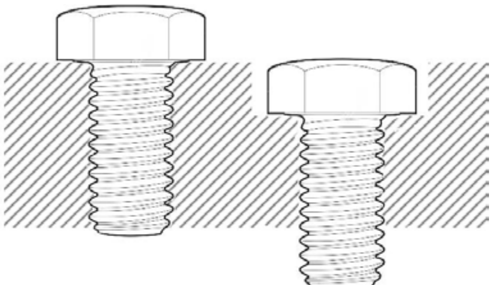

Figure 1. Left original situation with high bolt. Right the solution by placing the bolt lower.

causes a problem in the new model should be altered. New effects to solve the problem can be found in the Catalogues of Effects or using the Inventive Standards. For example a system needs a set screw. However the standard in the company are ISO-standard bolts. Using function analysis the set screw and its interactions is mapped. Hereafter the set screw is replaced with a standard bolt. The interaction with a slide that slides over the set screw, appears to be the problem. By creating an extra-large gap, the bolt is placed lower so the slide is not interrupted, but an ISO bolt can still be used. As depicted in figure 1.

## 4. Generalizing links between Design for Maintenance guidelines and TRIZ.

In the previous chapter eight guidelines were selected and discussed in detail. The guidelines all bring problems with them, and these problems can be solved using a TRIZ tool(s). In this chapter a closer look is taken at the eight analyzed guidelines, and it is investigated if patterns can be recognized. The purpose of the patterns it to determine if TRIZ can be used to support Design for Maintenance for not just the eight selected guidelines, but for all the guidelines. Based on the review of 8 guidelines linked to TRIZ, 4 recurring themes were identified. These themes are discussed in detail in the next paragraphs.

- Solving by changing a function
- Solving by splitting a function
- Solving by transferring a function
- Solving by resolving a contradiction

### *4.1. Change a function*

A (hard to maintain) component performs a certain function, and this function cannot be executed by another component. However, by changing the function, another (easy to maintain) component can be used. The result that maintenance activities are reduced and/or easier to execute.

The guidelines that support this theme are:

- Use standard, universally applicable components
- Design equipment in such a way that it can only be maintained in the right way
- Design-out moving parts
- Design for the use of standard tools

In order to change a function, Root Conflict Analysis and Inventive Principles can be used. With Root Conflict Analysis the main conflict why another component cannot be used is determined. The main conflict is hereafter resolved using the Inventive Principles. The result is that the function is changed, and thus a new component can be used.

### *4.2. Split a function*

A system contains a component that has multiple functions, but is difficult to maintain. By splitting the component into multiple components that are easier to maintain, the maintenance activities of the total system are reduced. The guidelines that support this theme are:

- Design modular
- Do not use coated, painted or plated components
- Design for the use of standard tools

In order to split the component without harming the total system, the functions and interactions of the current component should be mapped using Function Analysis. Hereafter the component can be split, while the functions and interactions are preserved. The Catalogues of Effects helps the maintenance engineer to split the components by finding new effects to deliver the function. And the Inventive Standards can help eliminate negative interactions with other components.

### *4.3. Transfer a function*

A (hard to maintain) component performs a certain function. By transferring the function to another component, the hard to maintain component can be eliminated. Guidelines that support this theme are:
- Design-out moving parts
- Avoid unnecessary components
- Do not use coated, painted or plated components

To make sure that the total system is not affected by trimming the component, the total system needs to be mapped using Function Analysis. Hereafter Functional Idealization is used to trim the hard to maintain components.

### *4.4. Resolve a contradiction*

Two of the eight selected guidelines are in contradiction with each other. Therefore the fourth theme is resolving a contradiction to solve a maintenance problem. The Inventive Principles should be used to solve the contradiction. The formulation of the contradiction differs per case, and should be reformulated for every problem.

### ***4.5. Conclusion***

It was found that the eight guidelines can be divided into four categories. Change a function, Split a Function, Transfer a Function, and Resolve a Contradiction.

## 5. Experimental validation

The four themes above are based on analysis of maintenance guidelines and TRIZ. To test the viability of the themes, seventeen maintenance problems from daily maintenance practice are tackled using one of the 4 themes. The problems (17) are acquired during an interview with a PhD student of the chair Maintenance Engineering of the University of Twente. The PhD student gathered the problems during industrial interviews. The problems depicted thus describe actual maintenance problems from industry.

Each maintenance problem is investigated and categorized into a theme. Hereafter the TRIZ tool of the theme is used to find a solution. This result of this process can be found in appendix B while a summary of the results is found in table 1. It depicts how often a theme is used to solve a problem. In the case that a problem can be solved using more than one theme, the most suitable theme is selected.

Table 1 Classification of the problems

| Category | Number of problems |
|---|---|
| Change a function | 2 |
| Split a function | 3 |
| Transfer a function | 2 |
| Resolve a contradiction | 10 |

Table 1 shows that a solution for all of the maintenance problems from industry can be found using one of the themes. This indicates that that the themes can be used to solve maintenance problems. Which also means that TRIZ tools can be used to support the maintenance guidelines. More than half of the problems are solved by resolving a contradiction.

## 6. Roadmap

In this chapter a roadmap is formulated that aids in solving maintenance problems by using TRIZ tools. The first step of this research was to prove if TRIZ can benefit maintenance guidelines. Now that this has been proven, a method is created how this can be done. It is clear that TRIZ is larger than only solving maintenance problems. Therefore it can be hard for the maintenance engineer to determine which TRIZ tool to use to solve a problem.

To aid maintenance engineers in doing this, a roadmap is created. The roadmap is a method to solve problems using both the Design for Maintenance guidelines and TRIZ. It is a 5 step roadmap that enables people with basic knowledge but limited experience with TRIZ, to use it to solve maintenance problems.

1. Clearly state the maintenance problem.
2. Determine the appropriate maintenance guideline.
3. State the problem that prevents applying the maintenance guideline in the current system.
4. Classify this problem into one of the four themes.
5. Solve the problem with the corresponding TRIZ tools.

Between step 2 and step 3 the maintenance engineer should check if the guideline itself solves the problem. When this is the case, TRIZ is not necessary to provide support and the guideline itself should be executed.

## 7. Conclusion and remarks

This research shows TRIZ tools can be used to support the 37 maintenance guidelines as established by the chair Maintenance Engineering at University of Twente. The result is a classification of TRIZ tools in 4 themes and a roadmap that aids maintenance engineers to solve problems using TRIZ and the maintenance guidelines. The roadmap ensures that maintenance engineers do not need knowledge and skills in all the tools and philosophy of TRIZ, in order to solve maintenance problems. This enables faster and less expensive, but also more innovative routes to find solutions to (maintenance related) problems.

There are several remarks on this research. Firstly, the roadmap was tested using two different cases, each describing maintenance design problems as found in industrial practice.

These small cases, for lack of space not described in this paper, illustrated that the roadmap is useful for generating new ideas and finding solutions. However, when more maintenance problems are investigated, the roadmap will evolve and become reliable. These problems should be worked out elaborately, and the solutions applied in practice. Secondly more maintenance guidelines should be linked with TRIZ tools. Furthermore it is possible that there are more themes to solve maintenance problems. Lastly, at this stage using the roadmap requires a basic understanding of the working principles and tools of TRIZ. It would be preferably if the roadmap could be expanded so all the tools are incorporated in the roadmap and are illustrated with examples from the world of maintenance. This could make a separate course on TRIZ for the maintenance staff unnecessary.

## Appendix A. 37 Guidelines for Design for Maintenance

1. Use materials that do not prolong maintenance activities
2. Use standard, universally applicable components
3. Use fasteners that accelerate maintenance activities
4. Ensure that the operators of installations are also able to maintain them
5. Provide sufficient space around the maintenance points
6. Design equipment in such a way that it can only be maintained in the right way
7. P that are regularly replaced need to be easy to handle
8. Guarantee safety by the design itself
9. Design modular systems
10. Use standard interfaces
11. Design the weakest link
12. Position components that often need to be maintained at an easily accessible place
13. Position the maintenance points close to each other
14. Design-out moving parts
15. Avoid unnecessary components
16. Avoid non-rigid parts / avoid rigid parts
17. Design for under stressed use
18. Provide redundancy
19. Overdesign components
20. Choose materials to resist environmental influences
21. Do not use coated, painted or plated components
22. Use components and materials with verified reliability
23. Design robust interfaces between components
24. Use parallel subsystems and components
25. Distribute workload equally over parallel subsystems or components
26. Use standard, universally applicable components
27. Avoid that expensive spare parts need to be in stock
28. Minimize the number of different types of fasteners
29. Save useful life time data
30. Avoid that secondary tasks consume a lot of time
31. Design for the use of standard tools
32. Do not use materials that affect people’s health
33. Design the system in such a way that adequate forecasting of maintenance is possible
34. Build monitoring equipment into the system
35. Ensure that as few as possible technicians are required to perform a maintenance task
36. Provide understandable maintenance instructions
37. Personnel with a variety of backgrounds should be able to execute maintenance

## Appendix B. Linking Guidelines for Design for Maintenance to sequences of TRIZ principle

Table 2. Linking Guidelines for Design for Maintenance to sequences of TRIZ principles

| ***Proposed sequence of TRIZ tools to be used*** | ***Applicable for Design for Maintenance rules no.*** |
|---|---|
| Root Conflict Analysis & Inventive Principles | #1, #2, #3, #10, #12, #14, #16, #19, #20, #22, #25, #26, #28, #32, #33 |
| Problem Perception Mapping, Root Conflict Analysis & Inventive Principles | #4, #6, #37 |
| Function Analysis & Function Idealization | #5, #8, #15, #21 |
| Function Analysis, Inventive Standards & Catalogues of Effects | #7, #31 |
| Function Analysis | #9, #11, #18, #24 |
| Function Analysis & Inventive standards | #23 |
| Inventive principles | #27 |
| Multiscreen diagram | #35 |

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