Reformulating a Semiconductor Information Problem with TRIZ

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Abstract

This paper will show the application of TRIZ to improve an information system in a semiconductor operation. Any industry or organization using sentence structure for recording observational findings in problem solving could apply this approach. The approach demonstrates synergy between Lean and TRIZ.

The semiconductor manufacturing process for computer chips is a complex sequence of many hundreds of processing steps on silicon wafers. At a number of points along the process, sample wafers are inspected by inspection equipment and defect images reviewed by technicians. Along with basic defect data fed automatically into a database, key interpretations of data are captured as a comment of several sentences. These comments are entered into several databases to enable usage by different customers. The comments were found to be an ineffective way to summarize the technician’s findings because analytical methods can not be applied to the information.

An improvement effort was started with Lean techniques, highlighting the opportunity to record comments only once, in a standardized manner. TRIZ Functional analysis resulted in a radically different and innovative improvement. Altshuller’s key premise is that correctly reformulating the problem is vital to an inventive solution. After formulating a contradiction, semantic analysis of all the words of typical comments revealed their specific functions and value of information to customers. This enabled trimming the comments altogether, replacing them with a set of categorical choices. The new fixed field categories provided new analysis possibilities associated with categorical data.

The resulting improvement increased the information value to customers, by adding new analysis functionality, and at the same time significantly reduced the effort to generate the information. Lean was used to highlight the area for improvement and TRIZ enabled a dramatic improvement of the system!

Case Study Background

As one of Intel’s semiconductor factories, Fab 17 has spent many years deploying lean techniques and realizing substantial business benefits from large numbers of lean improvements. In addition to regular use of basic lean tools and kaizen events, improvements have also been accomplished by teams formed by individuals who temporarily move from their regular job to a devoted lean improvement initiative for 3-6
month intervals. The following work was initiated out of one of these lean teams.

This lean effort was focused on improving quality methods, procedures, and systems. One key component of the overall quality effort is the work performed by Defect Metrology (DefMet) Technicians. These technicians are responsible for taking sample product lots to inspection tools which measure the amount of defects seen at that point in the manufacturing process. The numerical values of defect levels and defect positions are automatically fed into a database for later analysis. Next, the technician reviews the defects to classify the types of defects seen and records the results in the defect database. The most significant function of the DefMet technician is the human intelligence they apply to these results when a lot is flagged as ‘failing’ for a high defect level. The technician assesses the defect results along with other sources of information to make a final disposition comment and when possible, identifies the equipment tool causing the issue. A lean top-down flowchart of this process can be seen below in Figure 1.

![Top-down Flowchart of Defect Operation](image)

**Figure 1: Top-down Flowchart of Defect Operation**

This flowchart was created by directly observing the process performed by many DefMet technicians. There were minor variations between each technician; a representative example of the work is shown above in the flowchart. The problem statement was obvious from this flowchart: *There is significant waste for the DefMet technician to enter the disposition comments into multiple databases.* The lean principles clearly identified this as waste that should be eliminated. The problem seemed almost trivial at first. There were two possible solution paths. One solution was to enter the disposition
comment into one database and an information technology solution found to populate the other databases from this one database. However, given the age of the information systems and historical differences in their setup, no viable solution could be offered by the Information Technology team. A second less advantageous solution was to require all customers of the disposition comments to reference a single database.

This led to identifying the key customers of the DefMet disposition comment: DefMet Engineers, Process Engineers, Yield Analysis Engineers, Manufacturing Technicians, Equipment Technicians, other DefMet Technicians. The timing and specific functions each customer required for the comments was summarized. The requirements demonstrated that no single database could meet all customer’s needs without requiring additional labor from the customer.

**Application of TRIZ Tools**

In our dedicated lean improvement work, many other improvements were made for the Defect Metrology team but the above problem remained. It was decided to attack the problem utilizing basic TRIZ tools following the process shown in Figure 2.

![Figure 2: Steps for TRIZ Analysis](image)

To begin the TRIZ process the problem statement above was modified: *To transfer key information associated with disposition comments for a failing lot, DefMet technicians have to type excessive descriptions of findings in multiple database systems wasting resources.* Next a TRIZ Functional Model was built as shown in Figure 3.
In this model, in addition to the tasks required by the DefMet technician to assimilate the knowledge to feed the disposition comment (which was considered to be the primary object of function) the comment was followed to the customers (who were considered part of the super system). There were several system connections feeding the DefMet technician that were identified as insufficient while the connections to the multiple database systems were considered excessive. Upon investigation, it was also determined that in many cases the system containing the comment was also considered insufficient to the customers, although that had not yet been identified as part of the problem. From this model, a trimming exercise (see Figure 4) was performed which showed the obvious need to trim the redundant data entry from the various databases to one. This result was the same one identified in the lean work and was not an acceptable solution for the customers.
For the next step in the TRIZ analysis, the Cause Effect Chain in Figure 5 was built.

**Figure 5: TRIZ Cause Effect Chain**

The Cause Effect Chain had a number of similar dead ends as seen with the lean analysis (namely a technical solution was possible but not feasible based on available resources), but one new perspective (on the far right) came to light: the data entry method to enter the comment as a sentence was not optimal. This analysis along with the functional model allowed a simplified problem statement to be written: *The data entry system to record information acquired by DefMet technicians to disposition a failing lot requires excessive work to document and is insufficient for customer's use.*

**Reformulated Problem**

Altshuller stated that some problems are “solved automatically as soon as the problem’s formulation is stated precisely.”\(^2\) Certainly this problem was close to that category. The above simplified problem was rewritten as an Engineering Contradiction: *If the disposition data entry method is simplified then the DefMet technician’s workload is reduced but customers will have loss of information.* From this statement, the parameters to use in Altshuller’s Matrix were identified and the recommended Inventive Principles to apply to problem were found (see Figure 6).
Improving Parameter | Worsening Parameter
--- | ---
Ease of Operation | Loss of Information

<table>
<thead>
<tr>
<th>Inventive Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asymmetry</td>
<td>Change the shape of an object from symmetrical to asymmetrical.</td>
</tr>
<tr>
<td>Preliminary Action</td>
<td>Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.</td>
</tr>
<tr>
<td>Cheap Short-living Objects</td>
<td>Replace and inexpensive object with a multiple of inexpensive objects, comprising certain qualities.</td>
</tr>
<tr>
<td>Blessing in Disguise</td>
<td>Use harmful factors to achieve a positive effect.</td>
</tr>
</tbody>
</table>

**Figure 6: Altshuller’s Matrix Parameters and Recommended Inventive Principles**

For this problem, the **object** is the disposition comment. The most applicable Inventive Principle is **Preliminary Action**, which points to pre-arranging objects as a solution. So how could the comment be pre-arranged? The obvious solution at this point was to eliminate the sentence structure for comments and replace it with fixed field categories of information. Since a good solution was found the physical contradiction was not pursued. But formulating a practical manufacturing solution to fit this concept was no small task.

**Solutions and Secondary Problems**

As with many inventive solutions, the breakthrough idea can be weighed down with secondary problems. Key to the concept success was an accurate understanding of the contents of the comments. So the next step was a semantic analysis of a representative sample of DefMet disposition comments. **Figure 7** shows a pareto of the top 50 words from the semantic analysis.
The top 50 words represented over 52% of total word usage in the comments. Right away the analysis pointed out the lack of value with the top words such as *lot, on, for, & and*. While these words may be required for sentence structure, when you think of the function of the disposition process for the DefMet technician to transfer knowledge to the customers, they are not needed. The customer knows the problem relates to a *lot*. The customer knows the defects are *on* the wafer. To get a better sense of the functions of the words and to begin the process of determining the categories, the top 50 words were classified by general category in Figure 8.

![Figure 8: Word Category for Disposition Comments](image)

The analysis shows there were thousands of prepositions and verbs that had no real value. The primary word category that has value is the noun so this was further analyzed in Figure 9.

![Figure 9: Pareto of Nouns used in Disposition Comments](image)

Although nouns in general provide the most value as they typically provide the categorical type of information customers need, the top noun *lot* was not value-added. So
when all the top 50 words were assessed together it was found that only about 22% of the words added unique value to the customer. The value that the customer was looking for was a detailed specific type of description typically limited to one or two words for each type of detail. These value added words were grouped together and shown to the DefMet technicians along with customers of the disposition comments.

From this work, a set of 17 categorical fields were determined which had a set of fixed possible selections. Some additional supporting fields were also added that were open to any typed text. Each field had a label with a title describing the categorical choices which was previously a part of the sentence structure. An example of a category is the spatial pattern observed on the defect wafer map. While some automated spatial pattern recognition programs can match general patterns, often the human interpretation is still of the highest value as the technician can view all the wafers in a lot together and can easily interpret subtle differences that point to different manufacturing equipment tools as a source. Previously this human interpretation was embedded in the comment but now it became a fixed category that the technician simply selected allowing for it to be included in later analysis.

When it was assessed where to store this new categorical field and how to meet the customer’s needs, it was determined the best place was the Lot Tracking System. A solution was determined that made it possible for technicians to enter this information into the system with fixed field categories and it was verified that reports could be generated to meet most of customer’s needs. Additionally, the new fixed fields became categories that could now be analyzed by our normal statistical tools which greatly increased the value of each piece of information. This analytical benefit is why the single database can meet most of the customer’s needs compared to the original sentence structure being in one database. One other system will still need some details copied to it in the near term but there are solution paths to eliminate this in the long term. It was verified that the number of keystrokes the technician had to type was reduced by 70%.

While there were many benefits as described above, there were complaints. The mechanisms the technicians had to follow in the Lot Tracking System for the data entry was not intuitive and even with the reduced keystrokes the technicians still could type the sentence structure faster than entering the categorical information. The basic issue was the Lot Tracking System was built in an old framework that does not support pull down menus making the data entry very cumbersome. So the request was made to develop a pull down menu system in a web format that could support getting the required categorical information into the same Lot Tracking database. This system further reduced keystrokes and greatly simplified the data entry method so it is completely intuitive.

While the full deployment of this new system is still pending, sample results from testing the new methodology are very promising.
The Generalized Problem

There are numerous ways to extend this work. For Intel’s business needs, there are many types of issues in and out of the factory where sentence structure is utilized to capture knowledge from problem workers. As with the semiconductor industry at large, Intel excels at making decisions based on numerical data; however, when the initial knowledge is not captured as unique pieces of data, it typically requires a person to read the information to make use of it. It is obvious that the problem really applies to any field of problem solving work. A more general problem statement is: *For knowledge suppliers, the knowledge capture mechanism needs to be efficient and simple but for knowledge customers the information needs to be precise to maintain a high signal-noise ratio.*

While semantic structure analysis has been around for decades with expert systems offering promise to deductively reason what is meant in sentence structure, the reality in technical environments is that it has been difficult to deploy these methods with success. One issue that creates substantial noise in knowledge systems and limit natural language processing efforts is the issue of variation in technical terminology and misspelling. For example, out of the thousands of words analyzed for this work, there were hundreds of words either misspelled or words with uncommon abbreviations.

It was not easy to funnel the problem presented in the paper into the most relevant associated field. Certainly there are some components that fit into the broad field of Knowledge Management. One knowledge management paper makes the following distinctions: “data is raw numbers and facts, information is processed data, and knowledge is information made actionable.” In our case the knowledge the technicians gained in the DefMet process was feeding forward systems to enable not only immediate action but potentially later action as well. However, a more precise field was found that fits this case better – the field of Knowledge Representation. Knowledge Representation is a “means by which we express things about the world, the medium of expression and communication in which we tell the machine (and perhaps one another) about the world.” So the fields that are advancing knowledge representation were studied in more detail.

In order to determine the best solutions to a generalized problem in TRIZ, we first try to determine the S curve of the field associated with the problem. Altshuller described this S-Curve as having 4 stages for technological systems (see Figure 10).
The initial reason to look at an S-Curve is to assess the stage for the technological system under consideration. Whether we consider the broad field of Knowledge Management or the more specific field of Knowledge Representation, both of these can be considered to be late in the Birth stage. From this assessment, we can still expect a large number of inventions and changes to the system environment before large scale growth. Another function of S-Curve analysis is to find a leading industry in the field. In searching for examples where knowledge representation may be moving into the Growth stage, there are several possibilities but one that was studied for comparison is electronic medical records for the health care industry. The information type includes a broad mixture of categorical information along with large amounts of sentence descriptions of case details and a small amount of numerical data (almost the opposite of the semiconductor industry information). Although the beginning of the digitization of health information was initially slow, the medical informatics industry is now growing at a rapid pace with the American Medical Informatics Association at more than 4000 members.\(^7\)

In looking for specific examples, the clinical software used to feed the initial patient symptoms, clinical observations, and physician’s assessment was examined. Open source software solutions are the easiest ones to view the detailed setup without auditing actual clinics. One open source clinical software is MEDICAL which is described as “The Universal Hospital and Health Information System.”\(^8\) Looking through the screen shots of the software, it can be seen that the majority of entries are either numerical entry for initial vital signs or test results or fixed field categories for everything from diagnosis to medications. There are a few sections for ‘discussion’ of the clinical visit. It is evident from this example that the system is providing the information supplier mostly categorical fields with limited discussion fields. The customers of this information will greatly benefit as computer analytical methods can be applied for individual patients over time as well as for larger clinical studies if the information is made anonymous. In addition to pull-down menu choices, ‘smart typing’ fields with instant matching results may further simplify the process.

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**Figure 10: S-Curve: The Life Cycle of a System**

![S-Curve diagram](image-url)
The interesting conclusion from the S curve analysis is if the original problem had been identified as a knowledge problem followed by examining industry leaders in the knowledge representation field, a similar result would have been achieved. This further supports Altshuller’s primary premise of TRIZ that for most problems a solution has already been generated. To be more precise, Altshuller defined 5 levels of invention and this solution was available within the bounds of a Level 1 or 2 invention if you consider the industry to be the knowledge industry. However, from the author’s initial perspective, the problem was thought of as a semiconductor industry problem and thus required a Level 3 invention. This demonstrates how critical the entire problem formulation process is because a solution could have been found much faster if it had been written as a knowledge problem. Still it was helpful from a post mortem perspective to confirm the solution from the broader knowledge industry and the general direction for future efforts. Other possibilities (e.g. Bayesian Networks) were also seen in various knowledge fields which show still further possible advancements for any industry with a knowledge problem (including the medical industry) but they are beyond the scope of this paper.

Conclusion

This paper has demonstrated the benefits of using TRIZ tools to help solve an issue highlighted by Lean methods. The lean lens was beneficial to highlight the waste in the DefMet operation. After finding that the obvious solutions were not possible due to business constraints, TRIZ tools helped generate inventive solutions.

The customers were brought into the picture with the TRIZ functional modeling. This enabled a contradiction to be formulated which led to the inventive principle of Preliminary Action and the concept of breaking the sentence up into pre-arranged parts. Categorical field choices were eventually determined to be the best way to accomplish this solution, which allows for a 70% reduction in keystrokes and associated non-value added words. Without any expertise in the knowledge industry, TRIZ helped to enable a solution that is a core component of the knowledge representation field. This result opens the door for further improvements by knowledge industry experts. Also S-curve analysis verified that the solution is in line with the best knowledge solutions currently working in other fields.

References


