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# TRIZ applied in product development project prioritization

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## Abstract

Methods for making prioritization decisions for allocation of limited resources are needed for managers responsible for prioritization of product development projects. This research investigates the use of TRIZ, a methodology for problem solving that originated in the former Soviet Union, in product development project prioritization. TRIZ tools can be divided into problem definition tools and problem transformation tools. Some of the problem definition tools, also called analytical tools, are beneficial in prioritization of projects. A project prioritization table has been developed that allows a manager to determine a score for each of the projects that are in the portfolio. The scoring in this table assumes that a more innovative project should receive higher priority because it will lead to higher margins, build higher barriers to entry from competitors and be easier to protect as intellectual property. Although the transformational TRIZ tools do not provide direct aid in the prioritization of projects, some are beneficial in determining how to better utilize the available resources.

## Introduction

King Solomon from ancient Israel is considered by many to have been the wisest person who ever lived. In 1st Kings, Chapter 3 a story is told about two women who come before Solomon to resolve an issue. The first woman claimed that she had a baby and three days later the other woman who lived with her in the same house also had a baby. One of the babies has died and this leads to the controversy. The first woman claimed that the second woman's baby died during the night because the second woman rolled over on top of her baby. The first woman further claimed that when the second woman awakened, she noticed that her child had died during the night. She took her dead baby and switched it with the baby of the first woman. The first woman said that when she awakened, she thought her child had died, but then in the daylight recognized that this was not her child, but the other woman's child. The first woman confronted the second woman and the second woman claimed that her child was the one who was still alive. In front of King Solomon, both claimed the living child as their own. Solomon was faced with the dilemma of determining the mother of the living child. He called for an aid to bring him a sword. When the sword arrived, Solomon said that he would cut the baby in half and then each mother could a have half of the child. The first mother cried out for Solomon not to cut the child in half. She withdrew her claim and asked that the child be given to the second woman. The second woman said that it was fair to split the child between the two of them. Solomon then knew that the true mother was the first woman and that the second woman was an imposter. The child was given to the first woman and news of Solomon's wisdom grew throughout the world.[1]

Often in the business world of product development project prioritization, a similar type of dilemma is faced, but the best results are usually not obtained. In prioritization, the resources of the entity, be it development lab, marketing, or a whole small business, are represented by the baby. The inventors or owners of competing products or projects are represented by the two women. Finally, the team or person responsible for determining which project gets the funding and other resources required to bring the project to maturity is playing the role of Solomon. In many cases these competing projects may all be viable and ultimately lead to profits for the business, but cutting the baby in half or splitting the resources between all available projects leads to a dead baby or projects that never deliver benefits to the business. Rarely is one project owner or team going to feel so certain of the other project's success, and thus the success of the business entity, that they will offer to give their own resources up to ensure the success of the other project. Therefore, tools are needed by people in management that allow them to make the best possible decision when they are limited by manpower, time, and money as to which project should receive the resources and bulk of the attention. This research investigates the possibility of using TRIZ as a tool for project prioritization.

## Chapter 1 TRIZ

TRIZ is an acronym that comes from the Russian phrase "teorija rezhenija izobretatelskih zadach" which is translated into English as the theory of innovative problem solving.[2] It is a systematic approach to problem solving that was developed in the former Soviet Union by a man named Genrich Altshuller. Altshuller worked in the Patent Office for many years. During his time there he studied thousands and thousands of patents. He determined that all innovative (defined by not merely building or adding on to existing technology) surges in technology seemed to follow a limited number of specific patterns of evolution. This was the case even if they represented inventions from totally different areas of science. The generic patterns of evolution that were used in one discipline could potentially be used in another discipline. Basically he determined that by taking a specific problem and abstracting it into a more general problem, a general solution for a set of problems could be found. Then by performing an inverse abstraction to the original specific problem, a specific solution could be determined. An example of a principle used in TRIZ is the principle of self-service. Self-service of course has implications in the fast food industry as the customer also becomes the waiter or waitress. This principle was not used until Ray Kroc of McDonald's fame realized its potential. An example of self- service in an industrial setting is to use a by-product which might also be considered an "invisible resource" to help serve the use of the overall system. Capturing heat from exhaust gases and using it to pre-heat material is an example of utilizing the self- service aspects of the system for more efficient overall operation.

There have been many different uses of TRIZ in different settings, but the majority of its use has been in the manufacturing or engineering arena. Not many articles on business uses of TRIZ can be found especially when one considers the specific application in product or project portfolio management. There will be more discussion on these few articles later, but first a better and more in depth understanding of TRIZ is required to investigate its use in this area. TRIZ has the ability to facilitate "out of the box" thinking. Sometimes this may mean considering something that does not seem to fit into our established norms. When you think of the definition of manufacturing, many different ideas may come to mind. A definition that I will give is that manufacturing consists of taking a raw material or materials and transforming them in such a way that value is added to them. These transformations may be mechanical, chemical, electrical, etc. in nature. With this definition in mind, consider the following idea of manufacturing. Recently in an article entitled, "TRIZ and Innovative Economics" by G.L. Filkovsky, President Bush's economic team used a principle from TRIZ called "the other way around" when workers in traditional service industries like fast food restaurants were classified as manufacturing employees because they chemically transformed one material into another when ground beef was converted into a hamburger patty during the heating process. When such manufacturing employees are considered, manufacturing jobs have actually been growing in the United States as opposed to declining as conventional wisdom would have it.[3] The intent here is not to cause a political discussion on the definition of manufacturing jobs, but to facilitate "out of the box" thinking. In the remainder of this chapter, I will consider and detail specific areas of traditional TRIZ. This centers on the idea of abstractions and includes the areas of contradiction, resources, ideality, patterns of evolution, and the table of innovative principles. When considering TRIZ, better solutions to problems might use abstractions to resolve a strong contradiction where the sum of the benefits or useful aspects increase and the harmful aspects decrease hopefully to the point of disappearing.

In studying the solutions that resulted in patents within the Patent Office Altshuller noticed that there were five levels of solutions. These levels are given below and copied from *An Introduction to Triz* by Stan Kaplan:

1. Standard
    a. Solution by methods well known within specialty
2. Improvement
    a. Improvement of an existing system, usually with some complication
    b. Methods from same industry
3. Invention inside paradigm
    a. Essential improvement of existing system
    b. Methods from other fields
4. Invention outside paradigm
    a. Creating new generation of a system
    b. Solution "not in technology, but in science"
5. Discovery
    a. Pioneer invention of an essentially new system
    b. Usually based on major discovery, new science[4]

From the standpoint of a business entity, a good solution is one that gives that company a competitive edge.[2] One can see that as the solution moves up the levels of solutions from 1 to 5 that the potential of the competitive edge increases substantially. The type of solutions gleaned from TRIZ in product and project portfolio management would fit in the level 3 type of solution. A level 5 type of solution typically involves some phenomenon previously unknown and often leads to the introduction of whole new industries. An example in recent history might be the use of lasers. Kaplan gives examples of level 4 solutions being solutions utilizing the thermal memory of certain materials, level 3 being the introduction of the automatic transmission in automobiles, level 2 being the use of a mirror in a welders mask to focus the light in required areas, and level 1 using something already present like increasing the thickness of insulation in a pipe for better resistance to heat transfer.[4]

Altshuller noticed that there seemed to be certain patterns of evolution within the development of technological systems. These are sometimes presented as laws, but in reality they are simply observations made by Altshuller and others. Rantanen[2] has summarized these as the six patterns given below:

1. Uneven evolution of systems
2. Transition to the macro-level
3. Transition to the micro-level or segmentation
4. The increase of interactions: introducing substances and actions
5. Expansion and convolution or trimming
6. Increasing the ideality of the system.

In this way ideality is defined as the sum of the benefits divided by the addition of the sum of the costs and the sum of the harmful effects. From the standpoint of ideality, Leonardo DaVinci said, "think of the end before the beginning." Kaplan[4] has a more extensive list that includes eight items from Altshuller's work as well as two additional items that he adds to the list. His list is given below:

1. Law of completeness of parts of a system
2. Law of energy conductivity in a system
3. Law of harmonization of rhythms
4. Law of increasing ideality
5. Law of uneven development of parts
6. Law of transition to a super-system
7. Law of transition from macro to micro level
8. Law of increasing substance field involvement

9. Law of Increasing dynamism
10. Principle of psychological inertia

It may appear that several of these are in contrast to each other. Specifically, the two concerning transition to a micro level or transition to a macro level, are in contrast, but they both represent potential patterns of evolutions. Not all solutions or inventive ideas will follow all of the patterns and actually may only follow one of the patterns, but these patterns give different points of view from which to look at the problems and consider possible solutions. Kaplan says that any complete system consists of an engine that provides energy, a working organ that performs the function of the system, a transmission that carries the energy from the engine to the organ, and a control organ that controls or steers the system.[4] The law of conductivity says that energy flow will become more efficient. The law of harmonization of rhythms says the system will evolve towards more harmony. Ideality is approached when the sum of the benefits or useful effects increases and the sum of the harmful effects decreases to zero. The law of uneven development of parts suggests that different parts of the system will evolve at different rates. An example of this might be that speeds of computer chips have increased significantly, but the rest of the computers evolution has not kept pace with this speed enhancement. The law of transition to a super-system or the macro level suggests that a system may become a subsystem of a larger system. The transition from the macro to micro again can be seen in the evolution of a computer from being huge and filling a building to fitting on a desktop. The eighth law or substance field involvement suggests that two substances interact through a field and evolution is towards more perfect or efficient interaction.[4] This concept is discussed in greater detail later in this chapter. The law of increasing dynamism suggests that as evolution in a system occurs, fixed or static parts become dynamic in ways that enhance the overall efficiency. An example given by Kaplan is with retractable landing gear on aircraft. The principle of psychological inertia suggests that people are resistant to change and will keep antiquated components for some time because they are not used to the innovation.[4,5] Often people are only willing to take baby steps in technology. An example of this is that the first cars often had a horse head fixture on the front. More recently cell phones started having internal antenna, but often manufacturers would incorporate a plastic antenna that could be raised or lowered to meet the perceived need of an external antenna.

A higher level of solution or inventive solution is typically found through the principle of solution by abstraction. This gets at the heart of the TRIZ concept and many of the other ideas or tools are ways of viewing this abstraction from different perspectives. A key portion of this is understanding the critical contradictions in the system that needs to be improved. A technical or complex contradiction is one in which while one parameter goes up or improves, the other parameter goes down or gets worse. A physical or simple contradiction is one in which a single object or entity exists in two different states or is both absent and present at the same time. An example would be something being both big and small simultaneously or being both light and heavy simultaneously. From a business standpoint in the company for which I work, we need to have a large sales force in order to sell the products, but as the size of the sales force goes up, the cost of operations also goes up. For a small business with critical cash flow issues, this is a significant problem. This is a technical contradiction because when one parameter improves, the size of the sales force, another parameter becomes worse, cost of operations. Altshuller studied many patents and determined that typically innovative solutions could fit into set patterns. A matrix of 39 parameters where a contradiction could be formed between one parameter improving and another getting worse was devised. A copy of this matrix is given in Appendix II. If the intersection of the improving parameter and the parameter getting worse is determined, an idea of principles used to solve similar problems in the past is given. There are a total of 40 such principles given in Appendix I. In the example given above regarding sales force and cost, the improving parameter number 26 or amount of substance, and the worsening parameter is number 23 or waste of substance. From the matrix it can be seen that the suggested innovative principles from similar problems in the past are numbers 3, 6, 10, and 24. One can look all of these up in the appendix, but number 24 is to use a mediator. More specifically it says to use an intermediary object to transfer or carry out an action. This is the principle we have used in that we have a strategic alliance with a company that has a sales force numbering around 100 people and a complementary product to ours. They buy and then re-sell our product using their distribution channels. This is a form of abstraction as a specific problem is abstracted into a more general problem using the 39 parameters. Then a group of potential general solutions is found. From this list a specific solution for our problem is found.

A way to better explain the idea of abstraction is to consider the quadratic equation. A specific equation is $x^2-x-6=0$. One can recognize that this is a specific example of the quadratic equation of the general form $ax^2+bx+c=0$. The abstract or general solution to this problem is $x=(-b\pm(b^2-4ac)^{1/2})/2a$. The specific answer to this problem is that $x=-2$ or $x=3$. In typical problem solving often the specific answer to a specific problem is achieved by trial and error. Utilizing TRIZ, an abstraction of the specific problem is made. Some operator is used to find an abstract answer to the abstract or general form of the problem. Then a specialized solution is derived from the abstract solution.[4] The idea behind using the 40 principles is to try and find a solution that causes both parameters to improve or avoid the technical contradiction. If that can be achieved, a truly innovative solution is obtained. Most TRIZ experts believe that using a technical or complex contradiction and the 40 principles, has approximately 40% efficiency in solving problems. For someone to solve a problem in this way, they have to understand what is good and what is bad with a particular situation. This demonstrates the concept of requirements in opposition to each other.[5] With an efficiency of only 40%, stronger tools are needed for solving more and tougher problems.

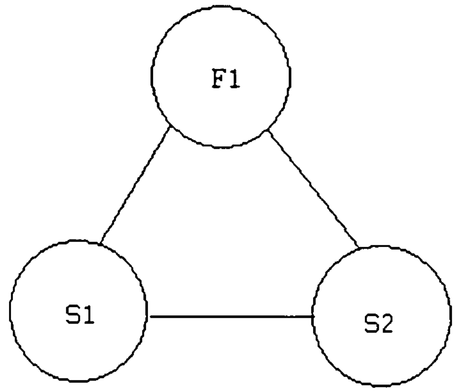
A simple contradiction exists when a characteristic exists in two opposing states or is both present and absent simultaneously. All technical contradictions can lead to at least one physical contradiction. In order to understand the physical contradiction from the technical contradiction, the idea of a control parameter is needed.[4] In the sales example given previously, the amount of sales should go up (good), but for that to happen the costs of the business go up (bad). In this example the control parameter is the size of the sales force or the existence of the sales force. In other words, simultaneously we want there to be a sales force present and not present or both big and small. This technical contradiction has been modified into a physical contradiction when considered using the control parameter of a sales force.

Innovative solutions to problems can be found using separation principles when a physical contradiction can be established. The three most powerful separation principles are separation in time, separation in space, and separation in scale meaning between the parts and the whole.[4] The idea of abstraction is used throughout TRIZ. Taking a problem and making a technical contradiction that can be solved is one level of abstraction which might be used to solve some set of problems. Taking a technical contradiction and converting it into a physical contradiction is a further abstraction that results in a larger set of problems that can be solved using these principles of separation. Although the principles of separation seem to be rather basic, they have tremendous power in their ability to stimulate inventive solutions to problems[4] or, as previously stated, give a different point of view from which to attack the problem.

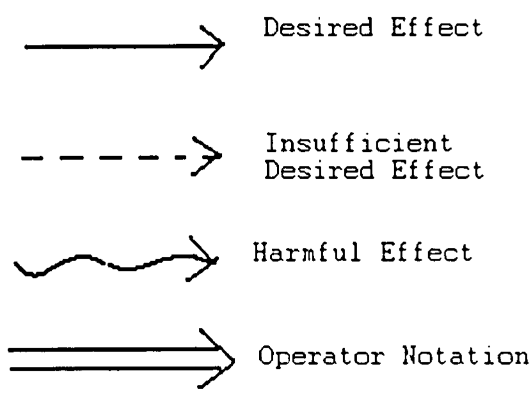
Another approach to solving inventive problems is through what Altshuller called substance and field theory or "Su-Field" theory for short. In all systems there are two substances that interact with each other through a field. These substances according to Kaplan[4] could be:

1. Two parts of the system
2. The system itself and what it acts upon or possibly its product
3. The system and its environment

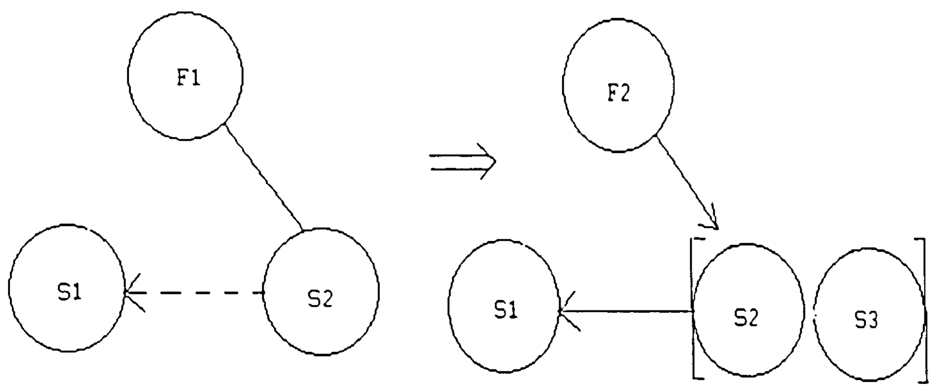
Examples of fields could be mechanical, acoustic, thermal, chemical, magnetic, electrical, or optical. The Su-field system can be modeled by the Su-field triangle. The Su-Field triangle is similar to an equilateral triangle in shape with the apex being the field and the two vertices on the base being each of the substances.




There are several notations used when viewing a Su-Field diagram depending on how the substances and field are connected to each other. A solid ray shows a desired effect. A dotted ray shows a weak desired effect or one that does not meet the whole desired effect. A wavy ray shows a harmful effect. Finally, two parallel rays with an arrow head on one end shows that an operator has been used to move up a level of abstraction. Each of these is shown below.




Of course this model of the system is very basic, but that means a larger pool of solutions in the abstracted form. If there are either insufficient desired effects or harmful effects, a solution that can lead to solid lines or all desired effects is an inventive solution. As previously discussed field types might be electrical, mechanical, optical, magnetic, etc. An example of a problem is one where the field acts on substance 2 but it has an insufficient desired effect on substance 1. A possible solution to that would be to either add a third substance in conjunction with substance 2 to reach the desired effect and/or possibly change the field type to a different one. This is depicted below by the original system on the left and then its abstracted solution on the right. Another example would be to have a field acting on substance two which leads to an undesired or harmful effect on substance one. In this case, a third substance might be added between substances 1 and 2 to mitigate this harmful effect. This is especially inventive and useful if substance 3 is a somewhat modified




version of substance one or two. In a plant where steel shot is moved pneumatically through pipe, the pipe becomes thinned by bombardment with the steel shot especially at elbows. A magnetic field is added at the elbow which causes a layer of the steel shot to stick to the wall at the bend. Now the erosion of steel is this layer of steel shot instead of the pipe itself. Therefore a new field has been added and a modified version of the harmful actor or substance has been utilized.

Previously ideality or considering the ideal solution has been discussed. Ideality is defined as the sum of the useful effects divided by the sum of the harmful effects.

Kaplan calls this the "SUH method, Modern TRIZ, or Ideation Methodology." All engineering systems have both harmful and useful outputs. SUH stands for system, useful and harmful, respectively. This is a very high level of abstraction that could potentially model every system given that all engineering systems have both useful and harmful outputs. The operators for reversing the abstraction based on this simple model are increase U or the useful outputs and decrease H or the harmful outputs. U and H, as operators, are more specific than simply desiring the ideal solution. The next layers down in the inverse abstraction given by Kaplan[4] are:

1. Given the system, find a way to eliminate or reduce H
2. Find a way to modify S that eliminates H while still yielding U
3. Find a way to obtain U without using S
4. Find a way to modify S that improves U without worsening H.

These operators seem extremely easy, but they cause the human mind to view the problem from different perspectives and think "outside of the box." Creativity is being able to train your mind to think in more inventive ways and view a problem and potential solutions from all angles. The harmful effects can be made more specific by considering undesired action and high expense attributes as a lower level of operator. Kaplan further specifies high expense attributes as:

1. Weight
2. Overall dimensions
3. Energy required
4. Energy wasted
5. Time wasted
6. System complexity
7. Monetary cost.

More specific operators for eliminating undesired action include:

1. Eliminate the cause of the undesired action
2. Exclude the source of the undesired action
3. Make use of the culprit of the undesired action
4. Substitute by using a model
5. Eliminate obstacles
6. Impact on the undesired action
7. Isolate the undesired action
8. Counteraction (compensation)
9. Parallel restoration
10. Anti-action
11. Vaccination
12. Use of feedback.

Kaplan[4] has made a list of more specific useful effects, U. This list is given below:

1. Reliability
2. Longevity
3. Mechanical strength
4. Speed of action
5. Stability of composition
6. Convenience
7. Productivity
8. Accuracy
9. Form
10. Universality
11. Degree of automation
12. Degree of adaptation.

All of these operators can be further broken down into additional sub-operators. There are software packages available with these further broken down, but I did not have access to the software packages for this research. If the harmful effects can be broken down into a series of smaller harmful effects that build on each other, then by eliminating one of these, all subsequent harmful effects are eliminated as well. Similarly, if there are a series of useful effects that build on each other, by improving one of these, all subsequent useful effects are also improved.

ARIZ is another acronym from Russian words that translates as the algorithm of inventive problem solving. This is a time consuming and complicated problem solving algorithm, but Clarke[5] has proposed a simplified version of ARIZ. The four steps in this process are copied below:

1. Defining what you want to achieve (Ideality)
2. Analyzing what you have to achieve the desired results (Resources and ideas for how to use them to achieve the desired results)
3. Then, if you have not achieved the desired results, determining what obstacles or contradictions prevent you from using all of the resources or solving the problem
4. And finally, changing the system or situation so you can use the resources you need to achieve the desired results (Resolving the Contradictions, Systems Approach thinking and the 40 Principles).

ARIZ is a systematic way to approach the whole problem as opposed to an individual tool to be used from the repertoire in the TRIZ library.

## Chapter 2 Product/Project Portfolio Management Literature

No existing literature could be found where TRIZ is being used as a tool for product development project portfolio management or specifically for the prioritization function within this management. Therefore, the literature reviewed is being divided into two chapters. This chapter will center upon literature dealing with product development project portfolio management with a strong bias towards this management in the innovation or product development area. Where there are concepts similar to ones used in TRIZ, they will be pointed out, but again no literature was found that linked portfolio management directly to TRIZ. Chapter 3 will center upon uses of TRIZ in business applications. All of these articles highlight business uses of TRIZ outside of portfolio management.

*Connecting the Dots*[6] by Cathleen Benko and F. Warren McFarlan is a book regarding the use of projects and product development as the company's currency for future growth. They include the idea of viewing portfolio management from a financial options standpoint. This allows for not guessing correctly all of the time. This option viewpoint is similar to the concept of using abstractions as is employed in TRIZ. Benko and McFarlan also discuss what they call "project chunking." Chunking is breaking down projects into discrete pieces. This can be used in conjunction with the stage-gate™ process as described in Cooper.[7] Chunking[6] is very similar to several concepts in TRIZ including separation in scale or between the parts and the whole. It is also similar to at least one of the patterns of evolution that Altshuller found to exist. The pattern of transition to the micro level (segmentation) is exactly what is occurring in chunking. Segmentation is also one of the 40 innovative principles in the Technical Contradiction Matrix. Benko and McFarlan[6] talk of the idea of "hub and spoke" projects where there is a commonality or basic project or portion of a project that can have spokes come out of it for more specific individual projects. This idea is similar to the ideas of universality and nesting in the 40 innovative principles matrix, transition to the macro level and to the micro level, depending on your perspective, in the patterns of evolution, and the general concept of abstraction that permeates most of TRIZ. Finally, Benko and McFarlan suggest building a library of reusable ideas and components which is very similar to Altshuller's study of commonalties within patents and patterns of evolution.

Robert Cooper[7] in the book *Product Leadership* suggests that the underlying issue in having leadership with new products is an issue of resource allocation. Much too often senior management distances itself from the issues of product development and is too focused on the short-term financial numbers considering product development as simply a research and development function. This is in clear contrast to one of the concepts of TRIZ which is to increase the ideality of the system from all perspectives instead of just one perspective. Also Cooper says that executive sponsored or executive pet projects too often get the resources even when they may not be the best projects on which to work. Cooper suggests using graphical depictions of projects to help in performing a risk-reward assessment. Specifically he demonstrates a risk-reward bubble diagram and several variants used by different enterprises. This diagram, depending on the axes chosen, can be a graphical depiction of the sum of the good benefits divided by the sum of the bad effects or more simply increasing the ideality. Finally, Cooper suggests that there should be a balance of the types of projects undertaken that is prescribed by the strategy of the enterprise. If the strategy is one of growth based on new technology or cutting edge projects in the portfolio, then there should be a larger number of new product projects underway. This balance of different projects is similar to the levels of solutions described in TRIZ.

*Ban the Humorous Bazooka* by Sebell and Yocum[8] discusses turning new ideas for products and services into a marketable reality. There is a distinction drawn in the book between creativity and innovation. Most companies have all the creativity that they need. It is the ability to turn that creativity into real products or services or innovation that is often missing. Sebell and Yocum address the idea of levels of solutions as discussed in TRIZ when they point out that it is just as important, if not more important, to have a high batting average as it is to be able to put the ball out of the park. They temper this thought by also saying that seeking only incremental innovation is an enemy of success through innovation. Certain organizations are more capable of and better at the lower levels of solutions. They say that transformational innovation often comes from start up companies because they do not have to fight battles that come from the old way of doing things. Of course this is very similar to the concept previously mentioned in the discussion of TRIZ on needing to overcome the organization's psychological inertia. In *Ban the Humorous Bazooka* mention is made of Wayne Gretzky being asked about his phenomenal success. Reportedly Gretzky said that he does not skate to where the puck is, but to where the puck is about to be. This concept, whether or not true, uses the concepts of abstraction, separation in time, and the ideal final solution. Sebell and Yocum also mention that in innovation an open mind set is required versus a yes-no mindset. This is like a higher form of abstraction. Finally, they mention that "creation requires a passion for paradox." This is clearly similar to the idea of contradictions from both technical and physical contradictions.

Preston Smith and Donald G. Reinertsen in *Developing Products in Half the Time*[9] say that opportunities should be sought to get products accomplished with less effort. Further, once a project is finished and off the list, it is no longer able to cause dilution of resources for the other projects on the table. Although not explicitly said here, it appears that the authors are getting at using the innovative principle of universality or moving to the macro level.

Philip Evans and Thomas Wurster in *Blown to Bits*[10] talk about blowing away the paradigm that says richness and reach are mutually exclusive. This in itself suggests a contradiction that when one of them gets better, the other must get worse. Of course this is one of the concepts used in technical contradictions. An example where this contradiction has been "blown to bits" is Dell Computer. They have achieved incredible reach through the internet while creating a rich relationship by allowing customers to custom build their own system. On the contrary, in the early 1900's Sears and Roebuck displaced a lot of mom and pop hardware stores by competing on reach, but they did not have the richness of individualized service from the small stores. Evans and Wurster comment that fast followers lose out five times more than do the entities that are early to market. This is similar to the TRIZ concept of organizational inertia impacting problem solving. There are also some implications of this statistic in the TRIZ concept of uneven evolution of systems. The idea of abstraction without a specific solution in mind is similar to the discussion in *Blown to Bits* about getting to market quickly. The statement attributed to Wayne Gretzky in Sebell and Yocum[8] that the winner does not always know what the final answer looks like, but instead understands the next couple of moves, is shown in this statistic. Being early to market shows desire to always move towards a more ideal final solution.

*Common Cents*[11] by Peter Turney is a book about activity based costing and to a lesser degree about activity based management. Although there are not many analogies that can be drawn between this book and concepts in TRIZ, the value received by customers gets at the concept of ideality. The value received by the customer is defined as "customer realization minus customer sacrifice." Customer realization is "the sum of product features, quality and service." Customer sacrifice is the cost experienced by the customer. This could include things like training cost associated with using a new piece of equipment or product. Understanding the costs from a customer's perspective is a different viewpoint from which to look at the problem. This is a concept that permeates TRIZ.

All of the previous discussion in this chapter has dealt with similarities of existing concepts in portfolio management to concepts in TRIZ. The rest of this chapter will contain some general concepts in portfolio management that may not have analogous concepts or similarities with TRIZ, but are worth mentioning as they may lead to a better final tool for portfolio management using TRIZ concepts. As Louis Pasteur said, "chance favors the prepared mind."[6] There seems to be a common thread through all sources on portfolio management that resource allocation is critical to success. Benko and McFarlan[6] say that you should play the hand that you are dealt and not dwell on past circumstances. The more resources that are placed on a project, the higher the likelihood of success. Resources are defined by commitment and time as opposed to only money. Smith and Reinertsen[9] write that typically the way resources are allocated is by taking the number of people available for project work and dividing it by the number of projects to be done. Instead, they write that the top priority project should be fully staffed first and then move on to the next. Continue this process until all human resources are being utilized. The way to determine if another person would benefit the top priority project is to ask "if I placed one more person on this project, would they be utilized?"[9] In *Developing Products in Half the Time* there is a distinction made between developing the right product and developing the product right. It further suggests that cutting development time in half in order to place twice the number of products on the market is not the correct approach. If the means of developing the product in half the time is through twice the resources, the effect on burn rate is typically the same.[9] When the number of projects on which an engineer is working goes from one to two, there value add time is increased. If the number of projects increases above two, the engineer's value-add time goes down. The reason that value add time goes up from one to two projects is that any time the engineer is waiting on some result or piece of the project from someone else, they would be idle if they only had one project. The top priorities are not getting the proper attention if the engineer has more than two projects. In the same way that a factory should not be run at 100% capacity because upsets will cause missed shipments, product development should not be run at 100% capacity as projects that merit development and resources will materialize and not be given appropriate resources.[9]

Products, or in the case of my work, formulations on the shelf that need testing and final development are work in process(WIP) and it is generally accepted that inventory costs money.[12] As in manufacturing when raw materials are converted to finished goods, inventory carrying costs rise. Smith[9] takes this concept of WIP in portfolio management a step further suggesting that the value of product development WIP diminishes faster than does manufacturing WIP because product development WIP is more perishable.

Some interesting statistics about the importance of portfolio management and the correct prioritization of projects are highlighted by Cooper[7]. Products five years old or less make up 32% of gross sales in the average company. The median return on investment for new products is 33%, payback period is 2 years, and market share is 35%. These numbers increase if averages instead of median numbers are used because there are some real high flyers that skew the numbers upward. This is an important area of study because 2.54% of gross domestic product is spent on research and development. In the chemical industry, which is closest to the industry in which I work, close to 7% of gross sales are spent on research and development. With these statistics, it is easy to see, "new product development is the manifestation of your business's strategy."[7]

# Chapter 3 Literature from Business Applications of TRIZ

There have been some uses of TRIZ outside of the problem solving and engineering arenas. Although none of these seem to be directly applicable to using TRIZ in product and portfolio management for the sake of prioritization, a review of this literature is warranted. Emily M. Smith[13] expands the idea of a technical contradiction to include the concept of an administrative contradiction. An example of what she would call an administrative contradiction results when higher quality is desired, but that also causes higher cost. In this article she also discusses the idea that a problem with the implementation of TRIZ comes from the fact that TRIZ itself is subject to the laws of evolution and has not reached maturity with respect to that evolution.

In "Converging in Problem Formulation," Cavallucci, et al.[14] discuss the two typical approaches to problem solving. One is the trial and error approach and the other is the convergent approach. TRIZ as a field proposes the convergent approach. This leads to a longer problem definition period; however, it yields fewer possible solutions. In the traditional or trial and error approach, there is not as much time spent on problem definition and many possible solutions are proposed. The best solution must then be determined.

Y. B. Karasik wrote an article entitled, "Towards a Contradiction Matrix for Economical Contradictions."[15] In this article Karasik proposes an application of TRIZ in an economic problem. Is a weak dollar or a strong dollar better? A weak dollar means more exports and domestic economic expansion. On the other hand, fewer foreign investments will be made in the U.S.A. when the dollar is weak causing a decrease in economic expansion. Karasik considers this contradiction with respect to Altshuller's contradiction matrix. The feature needing to improve or increase is the economy which corresponds to number 8 in the matrix, volume of non-moving object. The undesired feature is decrease in foreign investment which is similar to number 30, harmful factor acting on the object. The matrix given in Appendix II suggests principles 19, 27, 34, and 39. Of these principles 19 makes the most sense which Appendix I gives as periodic action. This suggests controlling the dollar in a way that leads to periods of a strong dollar and periods of a weak dollar. The dollar should be weak during peak manufacturing activities and strong at all other times. I am not sure how this is accomplished. Although Karasik does not specifically mention this, he has reached a higher level of abstraction because this has become a physical contradiction since the dollar should be both weak and strong.

Zinovy Royzen[16] wrote a paper presented to the Society of American Value Engineers(SAVE). In this paper the idea of trial and error methodology is discussed. It is suggested that in order for the methodology to be successful, the number of potential solutions needs to be between 10 and 15. Solutions derived from using the Laws of Evolution of Systems can be classified into three categories. These three categories are solutions that can be implemented "today, tomorrow or the day after tomorrow." Although Royzen does not consider the prioritization of products in the portfolio, this concept of when the solution can be implemented may be a beneficial tool for prioritization. Royzen discusses ideality or the ideal solution and specifically considers it from a value standpoint which includes cost reduction and improvement of the system. The need for brainstorming is eliminated or reduced as the participants are focused on the ideal final solution. Realizing that this paper was presented to SAVE helps to understand the emphasis on cost reduction and value improvement that comes from improving the system. Royzen believes that the higher the level of solution, which may correspond with the higher the level of abstraction, the better cost reduction or improvement of the system that can be obtained. He states that the Algorithm for Inventive Problem Solving (ARIZ) has been proven the best method for complex problem solving because of similarities in the Laws of Evolution across all fields of human activity. Although he does not specifically address the topic of this research, the idea of uses of TRIZ in many disciplines is put forth. Royzen is of course a big proponent of TRIZ and states in the paper regarding TRIZ, "It is a unique method for predicting development and new products and technologies." From the standpoint of prioritization and portfolio management, although not mentioned in the paper, it is clear that understanding the evolution of products and laws involved in technology evolution is meaningful for management to use as a tool when deciding where to direct their product development efforts and resources. It makes sense to use a tool that will indicate a likelihood of success in future products that are being developed. It further makes sense to put the significant resources on the highest potential products of the future. So even though Royzen does not specifically bring the idea of TRIZ in portfolio management out in his work, it certainly does point in that direction. A final quote from Royzen seems appropriate with respect to the idea of product development project prioritization. "The most reliable and effective way to renew a product or technology is to predict their development and new ones according to the Laws of Engineering System Evolution....In this case TRIZ can predict the new system that will change the existing one."

Darrell Mann[17] wrote a paper entitled "Systematic Win-Win Problem Solving in a Business Environment." Mann has written a 31 parameter matrix of the business contradiction matrix. I did not have full access to the matrix, but the 31 parameters are copied in Appendix III. Mann used the work of W. Edwards Deming to initiate this matrix. Deming viewed production of materials as a process. That process is broken into the following steps, "initial research, development and pre-production activities, the production process, the supply process and the post supply support activities." Mann developed these 31 parameters from successful business examples after breaking them down by the steps of the production of materials process. He studied the way that successful corporations in recent years have "challenged the prevailing trade-off, and conflicts of their industry and eliminated key contradictions their competitors assumed were inherent." I believe there is a trade-off in the effectiveness of an abstracted solution if the parameters of the matrix are made specific for each individual field of study. The level of abstraction has been reduced and the breadth of potential solutions may be diminished. By the same token if the practitioner is unsuccessful at performing a reverse abstraction to achieve a solution for the specific problem because of this breadth of possibilities from the higher level of abstraction, there still is no useable solution. Unfortunately there is no great database of successful solutions from a business standpoint like the one that exists within patent agencies of governments.

Ishida[18] has also devised a business idea database where concepts of inventions and problem solving were translated into more typical business principles. This was specifically accomplished with respect to "business/products strategy classification and information technology classification." This work was geared more towards business strategy and not product portfolio management even though the business strategy may also play an important role in deciding prioritization of resources for different projects. Ishida considered this approach with respect to Porter's five forces model.[19] The conclusions of Ishida[18] were that the business solutions provided by this approach might be different from those achieved with conventional tools, and when used with these other tools might expand business opportunities. My concern with this approach is that again there is no great database of success stories from which patterns can be determined, and therefore, the level of abstraction is reduced.

Zlotin et al.[20] have compiled a review of non-technical uses of TRIZ over the past 25 years. Their hope was to share the lessons learned in non-technical application of TRIZ. Unfortunately there has not been substantial application in the management and administrative areas as TRIZ came out of the former Soviet Union where those types of decisions were made by government entities. This situation was further exacerbated at Ideation, a TRIZ consulting firm and think tank, because there was a perceived, and probably real, bias against something from the former Soviet Union providing assistance in a capitalist society (U.S.A.) with respect to business decision making. Another obstacle was the lack of a large database of success stories from which to gain insight into trends or similarities in non-technical success stories analogous to the patent office with respect to technology. The work summarized in this paper includes applications in medicine, education, etc., as well as business. Unfortunately the majority of the business type applications deal with the evolution of organizations and are not directly applicable to the idea of prioritization of projects considered in this thesis. Zlotin et al. make an interesting distinction between tools used in the application of TRIZ that may be extremely beneficial to this work. They say that the tools are divided into two categories. The first category is analytical tools used in the defining or modeling of the problem. Examples of these types of tools are ARIZ and Su-Field analysis. Knowledge based tools fall into the second category. They are the tools that suggest the type of transformation to bring about the desired result. An example of this type of tool in TRIZ is the 40 innovative principles. This distinction may provide insight into which tools might be more readily applicable in portfolio management. The subversion approach is another concept discussed in this paper. They use it in the example of medical applications of TRIZ as well as technological applications. It considers performing "reverse brainstorming." A group considering the problem tries to brainstorm ways of making the product worse or "how to damage the part in such a way that it would be undetectable to quality control." They discuss an application in medicine where instead of asking, "How can a certain phenomenon be explained? One asks how can this phenomenon be obtained under existing conditions?" This gets back to the concepts mentioned in the first chapter on TRIZ of looking at the problem from different points of view.

Although there is not significant data about the application of TRIZ outside of technical areas, there are examples of its use outside this arena. No specific literature was found to deal with the utilization of TRIZ in product/portfolio management with respect to prioritization of resources. These other applications do suggest that further study in this prioritization arena is warranted. Similarly there have been uses of TRIZ concepts outside of the technology area without the users recognizing them as TRIZ concepts. The rest of this work will focus on the use of TRIZ in the application of portfolio management.

# Chapter 4 Analytical or Problem Definition TRIZ Tools

As previously discussed, Zlotin, et al.[20] advanced the concept that there are two different types of tools used in TRIZ. The first are those used in problem definition or modeling. They are also considered analytical tools and include the five levels of solutions, defining the relevant contradiction or contradictions, Su-Field Analysis and ARIZ. ARIZ is not specifically considered here as it is a combination of several of the other TRIZ concepts in a systematic approach for converging on a solution. The definition of contradictions includes both simple and complex contradictions. The second type is the transformational tools or knowledge based tools. Included in this set are the 40 innovative principles and associated matrix, six patterns of evolution, ideality or SUH, Kaplan's 10 items, and the three separation principles. There are two tools that could fit into both of these sets since they might be used in problem definition or modeling as well as give an idea about transformation. These two are the concept of psychological inertia and the laws of evolution. Both might be used to define the problem or fit the problem into a specific category, as well as, be used to transform the problem to yield a solution. Chapter 4 will discuss application of TRIZ in portfolio management using the analytical tools. Chapter 5 will discuss the application with transformational TRIZ tools.

This research into the use of TRIZ in the prioritization of resources for product development projects assumes that there is a conscious effort to modify an existing product or service in order to make something better or else there is a perceived need for some new product that the product development team is responsible for meeting. The manager trying to use the TRIZ tools must have the ability to choose between these projects and assign resources appropriately. Also, there is an assumption that the products proposed for development fit into the strategy and business plan for the company and there is a market for the products.

Kaplan[4] discussed Altshuller's five levels of solutions. These ranged from the lowest level being standard to the highest level being discovery. Typically a new product development project being considered for resource allocation can be placed into one of these levels of solutions. My belief is that the higher the level of solution used to bring about this new offering in the future portfolio of products, the higher the potential reward from that product. This may be balanced by the need for near-term sales of the business entity. In a start-up company, there may be a critical need for revenues in order to sustain the business or to receive venture capital. All of the resources of the start-up should not be placed on products or projects in the lower levels of solutions, but one or two products that may generate near-term sales could be helpful to sustain the business operations. Independent of the size or financial condition of the business, a lower level of solution is going to be harder to protect from an intellectual property standpoint and may not sustain the cost of obtaining a patent. Also the barriers to entry from competitors will be lower or possibly nonexistent with lower levels of solutions. For most well established business entities, the need for immediate revenue may be reduced and higher levels of solutions should receive most of the resources. Even smaller business concerns early in their evolution need to have a majority of the resources placed on the long-term, sustainable products that will create higher margins and have barriers to entry from competition. The use of Altshuller's five levels of solutions can be used as a tool for allocating resources in the product portfolio.

Whether or not a totally new product has been proposed for development or simply a modification is sought for an existing product, the TRIZ idea of a contradiction warrants study. If the problem being solved by the new product or service disintegrates a contradiction, then according to TRIZ principles it should be a more innovative solution. Further if the product to be developed can solve a physical contradiction, it should be even more innovative. If my assumption that the more innovative solutions will eventually lead to higher margins and better intellectual property protection is correct, then the concept of contradictions from TRIZ can be used as a tool when a manager needs to make a decision about the allocation of resources. If a contradiction or multiple contradictions will be solved by the project, then it should be higher on the priority list for receiving resources. Further if there is at least one, but possibly several, physical or simple contradictions that are solved, then it should be placed even higher on the priority list.

Su-Field theory is another analytical tool, or tool used in problem definition and modeling. This involves two substances that interact with each other through a field. There does not appear to be a direct means of using this effort in prioritization of resources. Kaplan[4] discusses that if there are either, insufficient desired effects or harmful effects, a solution leading to the desired effect is an inventive solution. Probably the level of abstraction required to use this type of model is too great for a manager to make a decision about the prioritization of projects or resource allocation. The most inventive solutions from Su-Field theory seem to be when a modified version of substance one or two can be used to bring about the desired effect. When this altered version is either a by-product or a hidden resource that has not been previously recognized the level of innovation seems to be greater. Typically a manager would not have the luxury of knowing that a proposed solution for a new product would fit into this category until after the work and design had already been accomplished. Therefore, this does not seem to be a reasonable tool for prioritization.

Psychological inertia is one of the tools that fit both into the analytical and transformational tools. If a proposed project for development of a product includes significant psychological inertia, it may take a longer time to reap financial benefits from its introduction into the marketplace. There are a couple of exceptions to this thought process that stand out. When a product or service is for a truly cutting edge technology, the idea of something "new" may in fact be a selling point even if there is psychological inertia to the contrary by lay people outside of that field. During the time of the internet boom, anything new that challenged the old way of thinking or doing business was just the sort of project that would receive outside funding and internal resources. The fact that the internet bust came along suggests that in reality most of these types of products did not warrant the attention and resources they received. There are other fields where the perception of being on the cutting edge sometimes requires something "new" that might experience significant psychological inertia. Two examples that come to mind are the business consulting field and academia. When there is a requirement to publish or perish, there needs to be a constant stream of new publishable ideas. Many of these ideas might encounter psychological inertia, but the "newness" is what defines them as good. In the business consulting industry where there is significant competition, a consultant wanting to be differentiated for marketing purposes needs to have at least some concepts that are "new." In such an example, there is psychological inertia, but it might be used to generate more business. Taking all of these factors into account, it seems that a project definition that suggests significant psychological inertia for most industries would be a project that should be lower on the priority scale; however, for extreme cutting edge industries and some service industries, psychological inertia should receive higher priority.

Royzen[16] suggested that the Laws of Evolutions of Systems can be classified into three categories. Those three categories are solutions that can be implemented "today, tomorrow or the day after tomorrow." When determining which development project should receive priority, these three categories of solutions are extremely significant. On the one hand, a solution that can be immediately instituted may not be as innovative, but returns may be realized almost immediately. A solution that can not be implemented until the day after tomorrow, may be the most innovative and potentially the most financially rewarding, but if revenue is needed immediately, it is not as beneficial. Understanding why the project is placed into one of these categories is essential in understanding how it fits into a prioritization scheme. If truly innovative products are the most financially rewarding products, and that is the reason it cannot be introduced until the day after tomorrow, then these are the products or projects that should be receiving the resources. Of course this assumes the company will be around the day after tomorrow to reap those benefits.

The final tool for consideration as an analytical or project definition tool is the type of transformational field that will be utilized in developing a new product. If this is known ahead of time, then it may be used in prioritizing the portfolio of projects available to a manager. As previously discussed in Chapter 1, there are different types of fields that are used to transform substances. The ones mentioned previously include mechanical, chemical, electrical, magnetic, acoustic, thermal, and optical. Additional types of fields could be gravitational, Van der Waals forces or surface tension. An argument could easily be made that acoustic and thermal fields are subsets of mechanical. Optical and magnetic fields are subsets of electrical. These subsets are typically more advanced, specialized, and innovative uses of a broader field. My contention is that when a field is used to solve a problem in order to develop a new product, the more innovative the type of field used, the more financially rewarding the product will be. Therefore, a product using a more advanced field to develop a new product should receive more resources when prioritization takes place.

The problem definition or analytical tools from TRIZ may be extremely beneficial to a manager trying to determine which product development projects in their portfolio should receive resources. This requires an ability to understand in advance the type of solution required to design or implement the new product. This will not always be possible. Even when the type of solution is known in advance, the determination of resource allocation may be dependent on the financial condition of the company and whether immediate sales are required for revenue generation. In general the projects that are more innovative will take longer to implement, but will generate higher margins and be easier to protect from an intellectual property standpoint. In the long-term this will be significantly more beneficial to the business entity.

# Chapter 5 Transformational TRIZ Tools

The second set of TRIZ tools that are considered in product development project prioritization are called transformational or knowledge based. These include the 40 innovative principles and associated matrix, six patterns of evolution, Kaplan's 10 items, the three separation principles and ideality or SUH. My research did not suggest a specific way to use these tools in the prioritization process, but they may be used to help make more efficient use of the resources that are available, resource utilization. Viewing the process of allocation of resources as a problem that needs to be solved, TRIZ may be able to provide insight into using the resources more efficiently.

The 40 innovative principles and associated matrix suggest solutions to problems that are based on Altshuller's years of study in the Patent Office. In this case the contradiction may be stated in several possible ways. If the number of projects available to work on goes up, the number of available resources per project goes down. Another way of stating it is that if the number of projects goes up, the number of projects making it to completion goes down. At the same time many projects leads to more successes, but many projects means that the resources are stretched too thin. The simple contradiction could be stated that at the same time, you want there to be both many projects to have higher chances of a successful one and fewer projects to insure there are enough resources to complete all of them. Using the matrix in Appendix II, the feature to change or improve is the number of projects. This potentially corresponds to several of the categories including the volume of a non-moving object, row number 8, or amount of a substance, row number 26. The undesired result or feature getting worse is productivity, column number 39. Based on the intersection of row 8 and column 39 the matrix suggests principles 2, 10, 35 and 37. Based on the intersection of row 26 and column 39 the matrix suggests principles 3, 13, 27 and 29. Principle 2 is extraction, or more specifically, extract only the necessary part. Based on this suggestion, is there some way that only the required part of the project could be accomplished with the resources that are available. Principle 10 is prior action. Determine a way to carry out the action either in full or in part in advance. Reverse abstracting this could include looking at previous projects to see if at least a portion has already been accomplished. If so, use the work from the previous project to more efficiently complete this project. Principle 35 is transformation of chemical and physical states of an object. No obvious use in project prioritization fits this principle. Principle 37 is thermal expansion and again this does not seem to be relevant to the problem at hand. The intersection of row 26 and column 39 suggests using principles 3, 13, 27 and 29. Principle 3 is local quality. This does not appear applicable to this problem. Principle 13 is inversion. This raises the question is there an opportunity to place no resources on a project and have the problem solve itself. It is not apparent what that would look like, but it opens the door to some different ways of viewing the problem. Principle 27 is an inexpensive short-life object instead of an expensive durable one. Is there some way to perform a shorter project with fewer resources that will accomplish the same thing as a full blown product development effort? Maybe there are some quick and easy tests that do not require significant resources that will help with a decision on the likelihood of success. Finally, principle 29 is use a pneumatic or hydraulic construction. This does not appear to be directly applicable to the problem at hand. Although I have given some specific ideas to the inverse abstraction, someone using TRIZ in this application should perform this exercise on their own because they would have a better understanding of the nuances of their specific prioritization problem. Their inverse abstraction may lead to much more beneficial results. They may find that the desired action and the undesired result in their contradiction statement is different from what I have suggested leading to a totally different principle or principles that could be used in solving their prioritization problem.

The six patterns of evolution from Altshuller are included with some minor variation in Kaplan's ten items. Similarly both the six patterns and ten items, include increasing the ideality of the system. Therefore, only Kaplan's ten items will be considered in the transformational tools. The idea of psychological inertia that fits into both analytical and transformational tools is also included in the ten items. Kaplan's first three laws of completeness of parts of the system, energy conductivity and harmonization of rhythms do not appear to be beneficial to a manager trying to prioritize product development projects. The law of increasing ideality suggests at least putting on paper what the projects and resources would look like if there were no constraints in the use of resources. Going through this exercise could provide some insight into how to avoid those constraints. The law of uneven development of parts could provide insight into a way of only working on a specific part of a development project that could fit into multiple future products. It would be rare that only assigning resources for a partial development would be beneficial, but there may be a few instances where it would make sense. The three laws of transition from macro to micro, micro to macro and increasing substance field involvement do not appear to be pertinent in trying to aid in the prioritization and utilization of resources. If there was some way to efficiently place all product development projects into one major project, but still only use the limited resources as if it was one smaller project, then the law of moving from micro to macro might be pertinent; however, this does not appear to be likely. The law of increasing dynamism suggests that utilization might improve through automation or rigorous product development systems. Currently, most organizations employ some type of stage gate process. Based on the law of increasing dynamism, systems such as these will increase utilization and make prioritization easier. The psychological inertia when viewed from the standpoint of utilization would suggest there is no way that all of the projects are going to receive proper prioritization and may discourage the proper allocation of resources on the highest priority projects. In other words the sky is falling and nothing is going to get done. Breaking this kind of attitude in the resources critical to project completion is necessary to make sure that resources are best utilized and the work is accomplished.

The separation principles of time, space and scale may be helpful in determining ways of solving the problem of prioritizing the allocation of resources or utilizing resources. If separation in time is considered, one might decide to work shifts on a project in order to most efficiently keep the work moving forward with the resources that are available. Previously, in the review of literature, the idea of asking whether or not one more person could be utilized on the top priority project before placing them on the next highest priority project was considered. If an extra shift was added in the Development Department, the answer to that question might be different. Separation in space might involve the development of a project being handed off from a group in the United States to a group in Asia at the end of the work day in the United States. This of course assumes there are resources available around the world. Finally, separation of the parts from the whole might include outsourcing some aspects of the development to another entity either within the original business concern or externally. This includes separation of parts of the design team from the whole design team, as well as, parts of the project from the whole project.

As is the case with the 40 principles, any decision about utilization or prioritization based on these other transformational tools is dependent upon the specific circumstances of the prioritization problem that needs to be solved. The inverse abstractions considered here are simply possible examples. The best decisions about how to complete the inverse abstraction are gong to be accomplished by the person most aware of the nuances of the specific problem. Although TRIZ transformational tools may be beneficial in increasing the efficiency or utilization of resources available, they really are not very beneficial in the tough prioritization decisions.

## Chapter 6 Conclusions and Recommendations

A distinction should be made between analytical and transformational TRIZ tools when considering product development portfolio management and prioritization. Some of the analytical TRIZ tools are directly applicable in prioritization of product development projects. The transformational TRIZ tools are not as applicable in prioritization, but some can be useful in determining how to best allocate or utilize the resources available for projects. When considering product development projects, an assumption is made that the most innovative projects are the ones that will lead to the highest returns for the company. This may not always be the case. Individual managers making prioritization decisions will need to determine if a modification needs to be made to this assumption in their specific situation. A second assumption is that the most innovative projects will have the highest barriers to entry from competitors and will be easiest to protect as intellectual property. It is worthwhile for a manager who has to make decisions about which projects receive the available resources to use these analytical tools when making their decisions. A method of ranking individual projects from the standpoint of their degree of innovation will be helpful to these managers. The specific analytical tools that this research has proposed as being beneficial to the decisions on prioritization include the five levels of solutions, the existence of contradictions, both simple and complex, psychological inertia and the type of field used in the solution. Based on these tools a score is determined that can be used to rank projects from an innovative standpoint. This ranking involves using a table with points awarded based on the analytical TRIZ tools that are considered beneficial in determining prioritization of projects. As a project moves up into the higher levels of solutions, it will receive more points. The increase in points received as a project moves up through the levels of solutions is not linear. Going from level one, standard, to level two, improvement, gives an increase of five points, but going from level two to level three, invention inside paradigm, is an increase of 10 points. This type of increase is a significant jump in the inventiveness of the product. Going from level three to level four, invention outside of paradigm, brings a similar 10 point jump. Going to level five, discovery, from level four delivers only a 5 point increase. This is because development of a totally new science, although extremely innovative, may not fit into the business strategy of the company and may require a significant increase in resources to bring the product developed to market. As the number of technical contradictions required to be resolved in development of the project increases, more points are awarded to the project. This point scheme increases in a linear fashion as the number of technical contradictions increases. If at least one physical contradiction is used to develop the product, then the solution is more innovative and 15 points are awarded. Psychological inertia scoring requires judgment on the part of the manager using the scoring table. This person must decide if the project will encounter little or no, some, or significant psychological inertia. If there is no psychological inertia, the project does not score any points for being innovative and should receive lower priority. If there is significant inertia, the project is probably very innovative, but overcoming the inertia may be difficult. Therefore, a project with some psychological inertia will receive more points than a project with significant psychological inertia. The type of field used in the development of a new product also gives an indication of the degree of innovation. Using more cutting edge fields increases the number of points received for a project. Not all types of fields are listed in the project prioritization table which means a person using the table may have to decide into which category of fields the specific field utilized should be placed. If no field is used, then no points are received. The number of points increases linearly with the degree of innovation of the category of field utilized. The potential score in the project prioritization table available from each of the analytical TRIZ tools is not equal. The maximum number of points available from the five levels of solutions is thirty; however, the maximum number of points available from solving a physical contradiction in the development of a product is fifteen points. This table is based on my judgment of importance of specific tools in the prioritization process. For each project the table given below should be completed with the highest scoring project receiving the highest priority.

| Project Prioritization Table | | | | | |
|---|---|---|---|---|---|
| | | | | | Project Score |
| Five Levels of Solutions | | | | | |
| Level 1 | Level 2 | Level 3 | Level 4 | Level 5 | |
| 0 points | 5 points | 15 points | 25 points | 30 points | |
| Number of Technical Contradictions | | | | | |
| One | Two | Three | Four | Five | |
| 0 points | 5 points | 10 points | 15 points | 20 points | |
| Use of Physical Contradiction | | | | | |
| No | | | | Yes | |
| 0 points | | | | 15 points | |
| Psychological Inertia | | | | | |
| One (little inertia) | | Two (some inertia) | | Three (significant inertia) | |
| 0 points | | 15 points | | 10 points | |
| Field Used in Solution | | | | | |
| Mechanical<br>Electrical<br>Chemical | | Magnetic<br>Thermal<br>Gravitational | | Optical<br>Acoustic<br>Van der Waals | |
| 10 points | | 20 points | | 30 points | |
| | | | | Total Score for Project | |

The transformational tools from TRIZ do not provide significant benefit in trying to prioritize projects, but at least some of them can provide insight into better utilization of the resources available. Specifically, the 40 innovative principles, mapping out how the ideal world would look with no constraints and unlimited resources, the laws of uneven development of parts and of increasing dynamism and the separation principles all may give an indication of better ways to utilize resources.

In order for TRIZ tools to be better utilized in prioritization of product development projects, the tools need to be used over time and a database of the successes and failures documented. The project prioritization table is a good start at a metric or analytical tool for determining which projects should receive priority. If access could be gained to a database of product development projects this table could be easily modified. After gaining experience with the use of the table, individual managers who are making the prioritization decisions would need to adjust assumptions and scoring based on the specifics of their particular business entity. Although TRIZ does not provide all the answers for how to prioritize projects in the product development arena it is a useful methodology that warrants future study for its effectiveness over time. With the project priority tool and better utilization of resources suggested, maybe the baby, or resources in this case, does not have to always be split by a sword, but a more efficient means of allocating resources can be achieved.

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Appendix 1
40 Innovative Principles

1. Segmentation
    a. Divide an object into independent parts
    b. Make an object sectional
    c. Increase a degree of an object's segmentation
2. Extraction
    a. Extract (remove or separate) a "disturbing" part or property from an object, or
    b. Extract the only necessary part or property
3. Local Quality
    a. Transition from a homogeneous structure of an object or outside environment (outside action) to a heterogeneous structure
    b. Have different parts of the object carry out different functions
    c. Place each part of the object under conditions more favorable for its operation
4. Asymmetry
    a. Replace a symmetrical form with an asymmetrical form of the object
    b. If an object is already asymmetrical, increase the degree of asymmetry
5. Consolidation
    a. Combine in space homogeneous objects or objects destined for contiguous operations
    b. Combine in time homogeneous or contiguous operations
6. Universality
    a. Have the object perform multiple functions, thereby eliminating the need for some other objects
7. Nesting
    a. Contain the object inside another which in turn is placed inside a third
    b. An object passes through a cavity of another object
8. Counterweight
    a. Compensate for the object's weight by joining with another object that has a lifting force
    b. Compensate for the weight of an object by interaction with an environment providing aerodynamic or hydrodynamic forces
9. Prior Counteraction
    a. If it is necessary to carry out some action, consider a counter-action in advance
    b. If by the problem statement an object has to have a tension, provide anti-tension in advance
10. Prior Action
    a. Carry out the required action in advance in full, or at least in part
    b. Arrange objects so they can go into action without time loss waiting for action (and from the most convenient position)
11. Cushion in Advance

   a. Compensate for relatively low reliability of an object by countermeasures taken in advance
12. Equipotentiality
   a. Change the condition of work so that an object need not be raised or lowered
13. Do it in Reverse
   a. Instead of an action dictated by the specification of the problem, implement an opposite action
   b. Make a moving part of the object or outside environment immovable and the non moving part moveable
   c. Turning the object upside down
14. Spheroidality
   a. Replace linear parts or flat surfaces with curved ones, cubical shapes with spherical ones
   b. Use rollers, balls, spirals
   c. Replace a linear motion with rotating movement, utilize a centrifugal force
15. Dynamicity
   a. Make characteristics of an object or outside environment automatically adjust for optimal performance at each stage of operation
   b. Divide an object into elements able to change position relative to each other
   c. If an object is immovable, make it moveable or interchangeable
16. Partial or Excessive Action
   a. If it is difficult to obtain 100% of a desired effect, achieve somewhat more or less to greatly simplify the problem
17. Transition into a New Dimension
   a. Remove problems in moving an object in a line by using two-dimensional movements (along a plane)
   b. Multi layer rather than single
   c. Incline the object or turn it on its side
   d. Project images onto neighboring areas or onto the reverse side of the object
18. Mechanical Vibration
   a. Set an object into oscillation
   b. If oscillation exists, increase its frequency, even as far as ultrasonic
   c. Use the frequency of resonance
   d. Instead of mechanical vibration use piezovibrators
   e. Use ultrasonic vibrations in conjunction with an electromatic field
19. Periodic Action
   a. Replace continuous action with a periodic one, or impulse
   b. If an action is already periodic, change its frequency
   c. Use pauses between impulses to provide additional action
20. Continuity of Useful Action
   a. Carryout an action without a break-all parts of an object should be constantly operating at full capacity
   b. Remove idle and intermediate motions
21. Rushing Through
   a. Perform harmful or hazardous operations at very high speed

22. Convert Harm into Benefit
    a. Utilize harmful factors or harmful effect of any environment to obtain a positive effect
    b. Remove a harmful factor by adding it with another harmful factor
    c. Increase the amount of harmful action until it ceases to be harmful
23. Feedback
    a. Introduce feedback
    b. If feedback already exists, reverse it
24. Mediator
    a. Use an intermediary object to transfer or carry out an action
    b. Temporarily connect an object to another one that is easy to remove
25. Self Service
    a. Make the object service itself and carry out supplementary and repair operations
    b. Make use out of waste of material and energy
26. Copying
    a. Use simple and inexpensive copy instead of an object which is complex, expensive, fragile or inconvenient to operate
    b. Replace an object or a system of objects by their optical copy, optical image. A scale can be used to reduce or enlarge the image
    c. If visible optical copies are used, replace them with infrared or ultraviolet copies
27. Dispose
    a. Replace an existing object by a collection of inexpensive ones, compromising other properties (longevity, for instance)
28. Replacement of a Mechanical System
    a. Replace a mechanical system by an optical, acoustical or odor system
    b. Use an electrical, magnetic, or electromagnetic field for interaction with the object
    c. Replace fields
        1. Stationary fields with moving fields
        2. Fixed, to those changing with time
        3. From randomed to structured
    d. Use a field in conjunction with ferromagnetic particles
29. Pneumatic or Hydraulic Construction
    a. Replace solid parts of an object by gas or liquid-these parts can use air or water for inflation or use air or hydrostatic cushions
30. Flexible Films
    a. Replace customary constructions with flexible membranes and thin film
    b. Isolate an object from outside environment with thin film or fine membranes
31. Porous Materials
    a. Make an object porous or use additional porous elements (inserts, covers, etc.)
    b. If an object is already porous fill the pores in advance with some substance
32. Changing the Color
    a. Change the color of an object or its surroundings

b. Change the degree of translucency of an object or surroundings
c. Use colored additives to observe objects or processes which are difficult to see
d. If such additives are already used, employ luminescent traces or tracer elements

33. Homogeneity
    a. Make objects interacting with a primary object out of the same material or material that is close to it in behavior
34. Rejecting or Regenerating Parts
    a. After it has completed its function or become useless reject or modify (e.g., discard, dissolve, or evaporate) an element of an object
    b. Restore directly any used up parts of an object
35. Transformation Properties
    a. Change an aggregate state of an object, concentration of density, the degree of flexibility, the temperature
36. Phase Transition
    a. Implement an effect developed during the phase transition of a substance. For instance, during the change of volume, liberation, or absorption of heat
37. Thermal Expansion
    a. Use expansion or contraction of material by heat
    b. Use various materials with different coefficients of heat expansion
38. Accelerated Oxidation
    a. Replace normal air with enriched air
    b. Replace enriched air with oxygen
    c. Treat in air or in oxygen with ionizing radiation
    d. Use ionized oxygen
39. Inert Environment
    a. Replace the normal environment with an inert one
    b. Carry out the process in a vacuum
40. Composite Materials
    a. Replace a homogeneous material with a composite one

# Appendix II
## Technical Contradiction Matrix

| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature to Improve | | Undesired Result | Weight of moving object | Weight of non-moving object | Length of moving object | Length of non-moving object | Area of moving object | Area of non-moving object | Volume of moving object | Volume of non-moving object | Speed | Force | Tension, pressure | Shape | Stability of object |
| 1 | Weight of moving object | | | | 15,8, 29,34 | | 29,17,3 8,34 | | 29,2 40,28 | | 2,8, 15,38 | 8,10, 18,37 | 10,36, 37,40 | 10,14, 35,40 | 1,35, 19,39 |
| 2 | Weight of non-moving object | | | | | 10,1, 29,35 | | 35,30, 13, 2 | | 5, 35 14, 2 | | 8,10, 19, 35 | 13, 29, 10, 18 | 13, 10 29, 14 | 26, 39, 1, 40 |
| 3 | Length of moving object | | 8,15, 29,34 | | | | 15,17, 4 | | 7,17, 4,35 | | 13,4, 8 | 17,10, 4 | 1,8, 35 | 1,8, 10,29 | 1,8, 15,34 |
| 4 | Length of non-moving object | | | 35,28, 40,29 | | | | 17,7, 10,40 | | 35,8, 2,14 | | 28,10 | 1,14, 35 | 13,14, 15,7 | 39,37,5 |
| 5 | Area of moving object | | 2,17, 29,4 | | 14,15, 18,4 | | | | 7,14, 17,4 | | 29,30, 4,34 | 19,30, 35,2 | 10,15, 36,28 | 5,34, 29,4 | 11,2,3, 39 |
| 6 | Area of non-moving object | | | 30,2, 14,18 | | 26,7, 9,39 | | | | | | 1,18, 35,36 | 10,15, 36,37 | | 2,38 |
| 7 | Volume of moving object | | 2,26, 29,40 | | 1,7, 4,35 | | 1,7, 4,17 | | | | 29,4, 38,34 | 15,35, 36,37 | 6,35, 36,37 | 1,15, 29,4 | 28,10,, 39 |
| 8 | Volume of non-moving object | | | 35,10, 19,14 | 19,14 | 35,8, 2,14 | | | | | | 2,18, 37 | 24,35 | 7,2, 35 | 34,28,5 ,40 |
| 9 | Speed | | 2,28, 13,38 | | 13,14, 8 | | 29,30, 34 | | 7,29, 34 | | | 13,28, 15,19 | 6,18, 38,40 | 35,15, 18,34 | 28,33,, 18 |
| 10 | Force | | 8,1, 37,18 | 18,13, 1,28 | 17,19, 6,36 | 28,10 | 19,10, 15 | 1,18, 36,37 | 15,9, 12,37 | 2,36, 18,37 | 13,28, 15,12 | | 18,21, 11 | 10,35, 40,34 | 35,10, 21 |
| 11 | Tension, pressure | | 10,36, 37,40 | 13,29, 10,18 | 35,10, 36 | 35,1 14,16 | 10,15, 36,25 | 10,15, 35,37 | 6,35, 10 | 35,24 | 6,35, 36 | 36,35 21 | | 35,4,,5, 10 | 35,33, 2,40 |
| 12 | Shape | | 8,10, 29,40 | 15,10, 26,3 | 29,34, 5,4, | 13,14, 10,7 | 5,34, 4,10 | | 14,4, 15,22 | 7,2, 35 | 35,15, 34,18 | 35,10, 37,40 | 34,15, 10,14 | | 33,1, 18,4 |
| 13 | Stability of object | | 21,35, 2,39 | 26,39, 1,40 | 13,15, 1,28 | 37 | 2,11, 13 | 39 | 28,10, 19,39 | 34,28, 35,40 | 33,15, 28,18 | 10,35, 21,16 | 2,35, 40 | 22,1, 18,4 | |
| 14 | Strength | | 1,8, 40,15 | 40,26, 27,1 | 1,15, 8,35 | 15,14, 28,26 | 3,34, 40,29 | 9,40, 28 | 10,15, 14,7 | 9,14, 17,15 | 8,13, 26,14 | 10,18, 3,14 | 10,3, 18,40 | 10,30,5 ,40 | 13,17, 35 |
| 15 | Durability of moving object | | 19,5, 34,31 | | 2,19, 9 | | 3,17, 19 | | 10,2, 19,30 | | 3,35, 5 | 19,2, 16 | 19,3, 27 | 14,26, 28,25 | 13,3, 35 |
| 16 | Durability of non-moving object | | | 6,27, 19,16 | | 1,10, 35 | | | | 35,34, 38 | | | | | 39,3, 35,23 |
| 17 | Temperature | | 36,22, 6,38 | 22,35, 32 | 15,19, 9 | 15,19, 9 | 3,35, 39,18 | 35,38 | 34,39, 40,18 | 35,6, 4 | 2,28, 36,30 | 35,10, 3,21 | 35,39, 19,2 | 14,22, 19,32 | 1,35, 32 |
| 18 | Brightness | | 19,1, 32 | 2,35, 32 | | | 19,32, 26 | | | | | | | | |
| 19 | Energy spent by moving object | | 12,18, 28,31 | | 12,28 | | 15,19 25 | | 35,13, 18 | | 8,15, 35 | 16,26, 21,2 | 23,14, 25 | 12,2, 29 | 19,13, 17,24 |
| 20 | Energy spent by non-moving | | | 19,9, 6,27 | | | | | | | | 36,37 | | | 27,4, 29,19 |

# Technical Contradiction Matrix Continued

| | Feature to Improve | Undesired Result | 14 Strength | 15 Durability of moving object | 16 Durability of non-moving object | 17 Temperature | 18 Brightness | 19 Energy spent by moving object | 20 Energy spent by non-moving object | 21 Power | 22 Waste of energy | 23 Waste of information | 24 Loss of information | 25 Waste of time | 26 Amount of substance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Weight of moving object | | 28,27, 18,40 | 5,34, 31,35 | | 6,20, 4,38 | 19,1, 32 | 35,12, 34,31 | | 12,36, 18,31 | 6,2, 34,19 | 5,35, 3,31 | 10,24, 35 | 10,35, 20,28 | 3,26, 18,31 |
| 2 | Weight of non-moving object | | 28, 2, 10, 27 | | 2,27, 19,6 | 28,19, 32,22 | 19,32, 35 | | 18,19, 28,1 | 15,19, 18,22 | 18,19, 28,15 | 5,8, 13,30 | 10,15, 35 | 10,20, 35,26 | 19,6, 18,26 |
| 3 | Length of moving object | | 8,35, 29,34 | 19 | | 10,15, 19 | 32 | 8,35, 24 | | 1,35 | 7,2, 35,39 | 4,29, 23,10 | 1,24 | 15,2, 29 | 29,35 |
| 4 | Length of non-moving object | | 15,14, 28,26 | | 1,40, 35 | 3,35, 38,18 | 3,25 | | | 12,8 | 6,28 | 10,28, 24,35 | 24,26 | 30,29, 14 | |
| 5 | Area of moving object | | 3,15, 40,14 | 6,3 | | 2,15, 16 | 15,32, 19,13 | 19,32 | | 19,10, 32,18 | 15,17 30,26 | 10,35, 2,39 | 30,26 | 26,4 | 29,30 6,13 |
| 6 | Area of non-moving object | | 40 | | 2,10, 19,30 | 35,39, 38 | | | | 17,32 | 17,7, 30 | 10,14, 18,39 | 30,16 | 10,35, 4,18 | 2,18, 40,4 |
| 7 | Volume of moving object | | 9,14, 15,7 | 6,35, 4 | | 34,39, 10,18 | 2,13, 10 | 35 | | 35,6, 13,18 | 7,15, 13,16 | 36,39, 34,10 | 2,22 | 2,6, 34,10 | 29,30, 7 |
| 8 | Volume of non-moving object | | 9,14, 17,15 | | 35,34, 38 | 35,6, 4 | | | | 30,6 | | 10,39, 35,34 | | 35,16, 32,18 | 35,3 |
| 9 | Speed | | 8,3, 26,14 | 3,19, 35,5 | | 28,30, 36,2 | 10,13, 19 | 8,15, 35,38 | | 19,35, 38,2 | 14,20, 19,35 | 10,13, 28,38 | 13,26 | | 18,19, 29,38 |
| 10 | Force | | 35,10, 14,27 | 19,2 | | 35,10, 24 | | 19,17, 10 | 1,16, 36,37 | 19,35, 18,37 | 14,15 | 8,35, 40,5 | | 10,37, 36 | 14,29, 18,36 |
| 11 | Tension, pressure | | 9,18, 3,40 | 19,3, 27 | | 35,39, 19,2 | | 14,24, 10,37 | | 10,35, 14 | 2,36, 25 | 10,36, 3,37 | | 37,36, 4 | 10,14, 36 |
| 12 | Shape | | 30,14, 10,40 | 14,26, 9,25 | | 22,14, 19,32 | 13,15, 32 | 2,6, 34,14 | | 4,6, 2 | 14 | 35,29, 3,5 | | 14,10, 34,17 | 36,22 |
| 13 | Stability of object | | 17,9, 15 | 13,27, 10,35 | 39,3, 35,23 | 35,1, 32 | 32,3, 27,15 | 13,19 | 27,4, 29,18 | 32,35, 27,31 | 14,2, 39,6 | 2,14, 30,40 | | 35,27 | 15,32, 35 |
| 14 | Strength | | | 27,3 26 | | 30,10, 40 | 35,19 | 19,35, 10 | 35 | 10,26, 35,28 | 35 | 35,28, 31,40 | | 29,3, 28,10 | 29,10,7 |
| 15 | Durability of moving object | | 27,3, 10 | | | 19,35, 39 | 2,19 4,35 | 28,6, 35,18 | | 19,10, 35,38 | | 28,27 3,18 | 10 | 20,10, 28,18 | 3,35, 10,40 |
| 16 | Durability of non-moving object | | | | | 19,18, 36,40 | | | | 16 | | 27,16, 18,38 | 10 | 28,20, 10,16 | 3,35,1 |
| 17 | Temperature | | 10,30, 22,40 | 19,13, 39 | 19,18, 36,40 | | 32,30, 21,16 | 19,15, 3,17 | | 2,14, 17,25 | 21,17, 35,38 | 21,36, 29,31 | | 35,28, 21,18 | 3,17,0, 39 |
| 18 | Brightness | | 35,19 | 2,19, 6 | | 32,35, 19 | | 32,1, 19 | 32,35, 1,15 | 32 | 19,16, 1,6 | 13,1 | 1,6 | 19,1,6, 17 | 1,19 |
| 19 | Energy spent by moving object | | 5,19, 9,35 | 28,35, 6,18 | | 19,24, 3,14 | 2,15, 19 | | | 6,19, 37,18 | 12,22, 15,24 | 35,24, 18,5 | | 35,38,9 ,18 | 34,23,6 ,18 |
| 20 | Energy spent by non-moving | | 35 | | | | 19,2, 35,32 | | | | | 28,27, 18,31 | | | 3,35, 1 |

# Technical Contradiction Matrix Continued

| | Feature to Improve | Undesired Result | 27 Reliability | 28 Accuracy of measurement | 29 Accuracy of manufacturing | 30 Harmful factors acting on object | 31 Harmful side effects | 32 Manufacturability | 33 Convenience of use | 34 Repairability | 35 Adaptability | 36 Complexity of device | 37 Complexity of control | 38 Level of automation | 39 Productivity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Weight of moving object | | 3,11, 1,27 | 28,27, 35,26 | 28,35, 26,18 | 22,21, 18,27 | 22,35, 31,39 | 27,28, 1,36 | 35,3, 2,24 | 2,27, 28,11 | 29,5, 15, 8 | 26, 30, 36, 34 | 28, 29, 26, 32 | 26, 35 18, 19 | 35, 3, 24, 37 |
| 2 | Weight of non- moving object | | 10,28, 8,3 | 18,26 28 | 10,1, 35,17 | 2,19, 22,37 | 35,22, 1,39 | 28,1, 9 | 6,13, 1,32 | 2,27, 28,11 | 19,15, 9 | 1,10, 26,39 | 25,28, 17,15 | 2,26, 35 | 1,28, 15,35 |
| 3 | Length of moving object | | 10,14, 29,40 | 28,32, 4 | 10,28, 29,37 | 1,15, 17,24 | 17,15 | 1,29, 17 | 15,29, 35,4 | 1,28, 10 | 14,15, 1,16 | 1,19, 26,24 | 35,1, 26,24 | 17,24, 26,16 | 14,4, 28,29 |
| 4 | Length of non-moving object | | 15,29, 8 | 32,28, 3 | 2,32, 10 | 1,18 | | 15,17, 27 | 2,25 | 3 | 1,35 | 1,26 | 26 | | 30,14, 7,26 |
| 5 | Area of moving object | | 29,9 | 26,28, 32,3 | 2,32 | 22,33, 28,1 | 17,2, 18,39 | 13,1, 26,24 | 15,17, 13,16 | 15,13, 10,1 | 15,30 | 14,1, 13 | 2,36, 26,18 | 14,30, 28,23 | 10,26, 34,2 |
| 6 | Area of non-moving object | | 32,35, 40,4 | 26,28, 32,3 | 2,29, 18,36 | 27,2, 39,35 | 22,1, 40 | 40,16 | 16,4 | 16 | 15,16 | 1,18, 36 | 2,35,0, 18 | 23 | 10,15, 17,7 |
| 7 | Volume of moving object | | 14,1, 40,11 | 25,26, 28 | 25,28, 2,16 | 22,21, 27,35 | 17,2, 40,1 | 29,1, 40 | 15,13, 30,12 | 10 | 15,29 | 26,1 | 29,26, 4 | 35,34, 16,24 | 10,6, 2,34 |
| 8 | Volume of non-moving object | | 2,35, 16 | | 35,10, 25 | 34,39, 19,27 | 30,18, 35,4 | 35 | | 1 | | 1,31 | 2,17, 26 | | 35,37, 10,2 |
| 9 | Speed | | 11,35, 27,18 | 28,32, 1,24 | 10,28, 32,25 | 1,218, 35,23 | 2,24, 35,21 | 35,13, 8,1 | 32,28, 13,12 | 34,2, 28,27 | 15,10, 26 | 10,28, 4,34 | 3,34, 27,16 | 10,18 | |
| 10 | Force | | 3,35, 13,21 | 35,10, 23,24 | 28,29, 37,36 | 1,35, 40,18 | 13,3, 36,24 | 15,37, 18,1 | 1,28, 3,25 | 15,1, 11 | 15,17, 18,20 | 26,35, 10,18 | 36,37, 10,19 | 2,35 | 3,28, 35,37 |
| 11 | Tension, pressure | | 10,13, 19,35 | 6,28, 25 | 3,35 | 22,1 37 | 2,33, 27,18 | 1,35, 16 | 11 | 2 | 35 | 19,1, 35 | 2,36, 37 | 35,24 | 10,14, 35,37 |
| 12 | Shape | | 10,40, 16 | 28,32, 1 | 32,30, 40 | 22,1, 2,35 | 35,1 | 1,32, 17,28 | 32,15, 26 | 2,13, 1 | 1,15, 29 | 16,29, 1,28 | 15,13, 39 | 15,1, 32 | 17,26, 34,10 |
| 13 | Stability of object | | | 13 | 18 | 35,24, 30,18 | 35,40, 27,39 | 35,19 | 32,35, 30 | 2,35, 10,16 | 35,30, 34,2 | 2,35, 22,26 | 35,22, 39,23 | 1,8, 35 | 23,35, 40,3 |
| 14 | Strength | | 11,3 | 3,27, 16 | 3,27 | 18,35, 37,1 | 15,35, 22,2 | 11,3, 10,32 | 32,40, 28,2 | 27,11, 3 | 15,3, 32 | 2,13, 28 | 27,3, 15,40 | 15 | 29,35, 10,14 |
| 15 | Durability of moving object | | 11,2, 13 | 3 | 3,27, 16,40 | 22,15, 33,28 | 21,39, 16,22 | 27,1, 4 | 12,27 | 29,10, 27 | 1,35, 13 | 10,4, 29,15 | 19,29, 39,35 | 6,10 | 35,17, 14,19 |
| 16 | Durability of non-moving object | | 34,27, 6,40 | 10,26, 24 | | 17,1, 40,33 | 22 | 35,10 | 1 | 1 | 2 | | 25,34, 6,35 | 1 | 10,20, 16,38 |
| 17 | Temperature | | 19,35, 3,10 | 32,19, 24 | 24 | 22,33, 35,2 | 22,35, 2,24 | 26,27 | 26,27 | 4,10, 16 | 2,18, 27 | 2,17, 16 | 3,27, 35,31 | 26,2, 19,16 | 15,28, 35 |
| 18 | Brightness | | | 11,15, 32 | 3,32 | 15,19 | 35,19, 32,39 | 19,35, 28,26 | 28,26, 19 | 15,17, 13,16 | 15,1, 19 | 6,32, 13 | 32,15 | 2,26, 10 | 2,25, 16 |
| 19 | Energy spent by moving object | | 19,21, 11,27 | 3,1, 32 | | 1,35, 6,27 | 2,35, 6 | 28,26, 30 | 19,35 | 1,15, 17,28 | 15,17, 13,16 | 2,29, 27,28 | 35,38 | 32,2 | 12,28, 35 |
| 20 | Energy spent by non-moving object | | 10,36, 23 | | | 10,2, 22,37 | 19,22, 18 | 1,4 | | | | | 19,35, 16,25 | | 1,6 |

# Technical Contradiction Matrix Continued

| | Feature to Improve | Undesired Result | 1 Weight of moving object | 2 Weight of non-moving object | 3 Length of moving object | 4 Length of non-moving object | 5 Area of moving object | 6 Area of non-moving object | 7 Volume of moving object | 8 Volume of non-moving object | 9 Speed | 10 Force | 11 Tension, pressure | 12 Shape | 13 Stability of object |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Power | | 8,36, 38,31 | 19,26, 17,27 | 1,10, 35,37 | | 19,38 | 17,32, 13,38 | 35,6, 38 | 30,6, 25 | 15,35, 2 | 26,2, 36,35 | 22,10, 35 | 29,14, 2,40 | 35,32, 15,31 |
| 22 | Waste of energy | | 15,6, 19,28 | 19,6, 18,9 | 7,2, 6,13 | 6,38, 7 | 15,26, 17,30 | 17,7, 30,18 | 7,18, 23 | 7 | 16,35, 38 | 36,38 | | | 14,2, 39,6 |
| 23 | Waste of information | | 35,6, 23,40 | 35,6, 22,32 | 14,29, 10,39 | 10,28, 24 | 35,2, 10,31 | 10,18, 39,31 | 1,29, 30,36 | 3,39, 18,31 | 10,13, 28,38 | 14,15, 18,40 | 3,36, 37,10 | 29,35, 3,5 | 2,14, 30,40 |
| 24 | Loss of information | | 10,24, 35 | 10,35, 5 | 1,26 | 26 | 30,26 | 30,16 | | 2,22 | 26,32 | | | | |
| 25 | Waste of time | | 10,20, 37,35 | 10,20, 26,5 | 15,2, 29 | 30,24, 14,5 | 26,4, 5,16 | 10,35, 17,4 | 2,5, 34,10 | 35,16, 32,18 | | 10,37, 36,5 | 37,36, 4 | 4,10, 34,17 | 35,3, 22,5 |
| 26 | Amount of substance | | 35,6, 18,31 | 27,26, 18,35 | 29,14, 35,18 | | 15,14, 29 | 2,18, 40,4 | 15,20, 29 | | 35,29, 34,28 | 35,14, 3 | 10,36, 14,3 | 35,14 | 15,2, 17,40 |
| 27 | Reliability | | 3,8, 10,40 | 3,10, 8,28 | 15,9, 14,4 | 15,29, 28,11 | 17,10, 14,16 | 32,35, 40,4 | 3,10, 14,24 | 2,35, 24 | 21,35, 11,28 | 8,28, 10,3 | 10,24, 35,19 | 35,1, 16,11 | |
| 28 | Accuracy of measurement | | 32,35, 26,28 | 28,35, 25,26 | 28,26, 5,16 | 32,28 3,16 | 26,28, 32,3 | 26,28, 32,3 | 32,13, 6 | | 28,13, 32,24 | 32,2 | 6,28, 32 | 6,28, 32 | 32,35, 13 |
| 29 | Accuracy of manufacturing | | 28,32, 13,18 | 28,35, 27,9 | 10,28, 29,37 | 2,32, 10 | 28,33, 29,32 | 2,29, 18,36 | 32,28, 2 | 25,10, 35 | 10,28, 32 | 28,19, 34,36 | 3,35 | 32,30 40 | 30,18 |
| 30 | Harmful factors acting on object | | 22,21, 27,39 | 2,22, 13,24 | 17,1, 39,4 | 1,18 | 22,1, 33,28 | 27,2, 39,35 | 22,23, 37,35 | 34,39, 19,27 | 21,22, 35,28 | 13,35, 39,18 | 22,2, 37 | 22,1 3,35 | 35,24, 30,18 |
| 31 | Harmful side effects | | 19,22, 15,39 | 35,22, 1,39 | 17,15, 16,22 | | 17,2, 18,39 | 22,1, 40 | 17,2, 40 | 30,18, 35,4 | 35,28, 3,23 | 35,28, 1,40 | 2,33, 27,18 | 35,1 | 35,40, 27,39 |
| 32 | Manufacturability | | 28,29, 15,16 | 1,27, 36,13 | 1,29, 13,17 | 15,17, 27 | 13,1, 26,12 | 16,40 | 13,29, 1,40 | 35 | 35,13, 8,1 | 35,12 | 35,19, 1,37 | 1,28, 13,27 | 11,13, 1 |
| 33 | Convenience of use | | 25,2, 13,15 | 6,13, 1,25 | 1,17, 13,12 | | 1,17, 13,16 | 18,16, 15,39 | 1,16, 35,15 | 4,18, 39,31 | 18,13, 34 | 28,13, 35 | 2,32, 12 | 15,34, 29,28 | 32,35, 30 |
| 34 | Repairability | | 2,27, 35,11 | 2,27, 35,11 | 1,28, 10,25 | 3,18, 31 | 15,13, 32 | 16,25 | 25,2, 35,11 | 1 | 34,9 | 1,11, 10 | 13 | 1,13, 2,4 | 2,35 |
| 35 | Adaptability | | 1,6, 15,8 | 19,15, 29,16 | 35,1, 29,2 | 1,35, 16 | 35,30, 29,7 | 15,16 | 15,35, 29 | | 35,10, 14 | 15,17, 20 | 35,16 | 15,37, 1,8 | 35,30, 14 |
| 36 | Complexity of device | | 26,30, 34,36 | 2,36, 35,39 | 1,19, 26,24 | 26 | 14,1, 13,16 | 6,36 | 34,25, 6 | 1,16 | 34,10, 28 | 26,16 | 19,1, 35 | 29,13, 28,15 | 2,22, 17,19 |
| 37 | Complexity of control | | 27,26, 28,13 | 6,13, 28,1 | 16,17, 26,24 | 26 | 2,13, 15,17 | 2,39, 30,16 | 29,1, 4,16 | 2,18, 26,31 | 3,4, 16,35 | 36,28, 40,19 | 35,36, 37,32 | 27,13, 1,39 | 11,22, 39,30 |
| 38 | Level of automation | | 28,26 18,35 | 28,26, 35,10 | 14,13, 17,28 | 23 | 17,14, 13 | | 35,13, 16 | | 28,10 | 2,35 | 13,35 | 15,32, 1,13 | 18,1 |
| 39 | Productivity | | 35,26, 24,37 | 28,27, 15,3 | 18,4, 28,38 | 30,27, 14,26 | 10,26, 34,31 | 10,35, 17,7 | 2,6, 34,10 | 35,37, 10,2 | | 28,15, 10,36 | 10,37, 14 | 14,10, 34,40 | 35,3, 22,39 |

# Technical Contradiction Matrix Continued

| | | Undesired Result | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feature to Improve | | Strength | Durability of moving object | Durability of non-moving object | Temperature | Brightness | Energy spent by moving object | Energy spent by non-moving object | Power | Waste of energy | Waste of information | Loss of information | Waste of time | Amount of substance |
| 21 | Power | | 26,10, 28 | 19,35, 10,38 | 16 | 2,14, 17,25 | 16,6, 19 | 16,6, 19,37 | | | 10,35, 38 | 28,27, 18,38 | 10,19 | 35,20, 10,6 | 4,34, 19 |
| 22 | Waste of energy | | 26 | | | 19,38, 7 | 1,13, 32,15 | | | 3,38 | | 35,27, 2,37 | 19,10 | 10,18, 32,7 | 7,18, 25 |
| 23 | Waste of information | | 35,28, 31,40 | 28,27, 3,18 | 27,16, 18,38 | 21,36, 39,31 | 1,6, 13 | 35,18, 24,5 | 28,27, 12,31 | 28,27, 18,38 | 35,27, 2,31 | | | 15,18, 35,10 | 6,3, 10,24 |
| 24 | Loss of information | | | 10 | 10 | | 19 | | | 10,19 | 10,19 | | | 24,26, 28,32 | 24,28, 35 |
| 25 | Waste of time | | 29,3, 28,18 | 20,10, 28,18 | 28,20, 10,16 | 35,29, 21,18 | 1,19, 26,17 | 35,38, 19,18 | 1 | 35,20, 10,6 | 10,5, 18,32 | 35,18, 10,39 | 24,26, 28,32 | | 35,38, 18,16 |
| 26 | Amount of substance | | 14,35, 34,10 | 3,35, 10,40 | 3,35, 31 | 3,17, 39 | | 34,29, 16,18 | 3,35, 31 | 35 | 7,18, 25 | 6,3, 10,24 | 24,28, 35 | 35,38, 18,16 | |
| 27 | Reliability | | 11,28 | 2,35, 3,25 | 34,27, 6,40 | 3,35, 10 | 11,32, 13 | 21,11, 27,19 | 36,23 | 21,11, 26,31 | 10,11, 35 | 10,35, 29,39 | 10,28 | 10,30, 4 | 21,28, 40,3 |
| 28 | Accuracy of measurement | | 28,6, 32 | 28,6, 32 | 10,26, 24 | 6,19, 28,24 | 6,1, 32 | 3,6, 32 | | 3,6, 32 | 26,32, 27 | 10,16, 31,28 | | 24,34, 28,32 | 2,6, 32 |
| 29 | Accuracy of manufacturing | | 3,27 | 3,27, 40 | | 19,26 | 3,32 | 32,2 | | 32,2 | 13,32, 2 | 35,31, 10,24 | | 32,26, 28,18 | 32,30 |
| 30 | Harmful factors acting on object | | 18,35, 37,1 | 22,15, 33,28 | 17,1, 40,33 | 22,33, 35,2 | 1,19, 32,13 | 1,24, 6,27 | 10,2, 22,37 | 19,22, 31,2 | 21,22, 35,2 | 33,22, 19,40 | 22,10, 2 | 35,18, 34 | 35,33, 29,31 |
| 31 | Harmful side effects | | 15,35, 22,2 | 15,22, 33,31 | 21,39, 16,22 | 22,35, 2,24 | 19,24, 39,32 | 2,35, 6 | 19,22, 18 | 2,35, 18 | 21,35, 2,22 | 10,1, 34 | 10,21, 29 | 1,22 | 3,24, 39,1 |
| 32 | Manufacturability | | 1,3, 10,32 | 27,1, 4 | 35,16 | 27,26, 18 | 28,24, 27,1 | 28,26, 27,1 | 1,4 | 27,1, 12,24 | 19,35 | 15,34, 33 | 32,24, 18,16 | 35,28, 34,4 | 35,23, 1,24 |
| 33 | Convenience of use | | 32,40, 3,28 | 29,3, 8,25 | 1,16, 25 | 26,27, 13 | 13,17, 1,24 | 1,13, 24 | | 35,34, 2,10 | 2,19, 13 | 28,32, 2,24 | 4,10, 27,22 | 4,28, 10,34 | 12,35 |
| 34 | Repairability | | 11,1, 2,9 | 11,29, 28,27 | 1 | 4,10 | 15,1, 13 | 15,1, 28,16 | | 15,10, 32,2 | 15,1, 32,19 | 2,35, 34,27 | | 32,1, 10,25 | 2,28, 10,25 |
| 35 | Adaptability | | 35,3, 32,6 | 13,1, 35 | 2,16 | 27,2, 3,35 | 6,22, 26,1 | 19,35, 29,13 | | 19,1, 29 | 18,15, 1 | 15,10, 2,13 | | 35,28 | 3,35, 15 |
| 36 | Complexity of device | | 2,13, 28 | 10,4, 28,15 | | 2,17, 13 | 24,17, 13 | 27,2, 29,28 | | 20,19, 30,34 | 10,35, 13,2 | 35,10, 28,29 | | 6,29 | 13,3, 27,10 |
| 37 | Complexity of control | | 27,3, 15,28 | 19,29, 39,25 | 25,24, 6,35 | 3,27, 35,16 | 2,24, 26 | 35,38 | 19,35, 16 | 19,1, 16,10 | 35,3, 15,19 | 1,13, 10,24 | 35,33, 27,22 | 18,28, 32,9 | 3,27, 29,18 |
| 38 | Level of automation | | 25,13 | 6,9 | | 26,2, 19 | 8,32, 19 | 2,32, 13 | | 28,2, 27 | 23,28 | 35,10, 18,5 | 35,33 | 24,28, 35,30 | 35,13 |
| 39 | Productivity | | 29,28, 10,18 | 35,10, 2,18 | 20,10, 16,38 | 35,21, 28,10 | 26,17, 19,1 | 35,10, 38,19 | 1 | 35,20, 10 | 28,10, 29,35 | 28,10, 35,23 | 13,15, 23 | | 35,38 |

# Technical Contradiction Matrix Continued

| | | Undesired Result | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feature to Improve | | | Reliability | Accuracy of measurement | Accuracy of manufacturing | Harmful factors acting on object | Harmful side effects | Manufacturability | Convenience of use | Repairability | Adaptability | Complexity of device | Complexity of control | Level of automation | Productivity |
| 21 | Power | | 19,24, 26,31 | 32,15, 2 | 32,2 | 19,22, 31,2 | 2,35, 18 | 26,10, 34 | 26,35, 10 | 35,2, 10,34 | 19,17, 34 | 20,19, 30,34 | 19,35, 16 | 28,2, 17 | 28,35, 34 |
| 22 | Waste of energy | | 11,10, 35 | 32 | | 21,22, 35,2 | 21,35, 2,22 | | 35,22, 1 | 2,19 | | 7,23 | 35,3, 15,23 | 2 | 28,10, 29,35 |
| 23 | Waste of information | | 10,29, 39,35 | 16,34, 31,28 | 35,10, 24,31 | 33,22, 30,40 | 10,1, 34,29 | 15,34, 33 | 32,28, 2,24 | 2,35, 34,27 | 15,10, 2 | 35,10, 28,24 | 35,18, 10,13 | 35,10, 18 | 28,35, 10,23 |
| 24 | Loss of information | | 10,28, 23 | | | 22,10, 1 | 10,21, 22 | 32 | 27,22 | | | | 35,33 | 35 | 13,23, 15 |
| 25 | Waste of time | | 10,30, 4 | 24,34, 28,32 | 24,26, 28,18 | 35,18, 34 | 35,22, 18,39 | 35,28, 34,4 | 4,28, 10,34 | 32,1, 10 | 35,28 | 6,29 | 18,28, 32,10 | 24,28, 35,30 | |
| 26 | Amount of substance | | 18,3, 28,40 | 13,2, 28 | 33,30 | 35,33, 29,31 | 3,35, 40,39 | 29,1, 35,27 | 35,29, 25,10 | 2,32, 10,25 | 15,3, 29 | 3,13, 27,10 | 3,27, 29,18 | 8,35 | 13,29, 3,27 |
| 27 | Reliability | | | 32,3, 11,23 | 11,32, 1 | 27,35, 2,40 | 35,2, 40,26 | | 27,17, 40 | 1,11 | 13,35, 8,24 | 13,35, 1 | 27,40, 28 | 11,13, 27 | 1,35, 29,38 |
| 28 | Accuracy of measurement | | 5,11, 1,23 | | | 28,24, 22,26 | 3,33, 39,10 | 6,35, 25,18 | 1,13, 17,34 | 1,32, 13,11 | 13,35, 2 | 27,35, 10,34 | 26,24, 32,28 | 28,2, 10,34 | 10,34, 28,32 |
| 29 | Accuracy of manufacturing | | 11,32, 1 | | | 26,28, 10,36 | 4,17, 34,26 | | 1,32, 35,23 | 25,10 | | 26,2, 18 | | 26,28, 18,23 | 10,18, 32,39 |
| 30 | Harmful factors acting on object | | 27,24, 2,40 | 28,33, 23,26 | 26,28, 10,18 | | | 24,35, 2 | 2,25, 28,39 | 35,10, 2 | 35,11, 22,31 | 22,19, 29,40 | 22,19, 29,40 | 33,3, 34 | 22,35, 13,24 |
| 31 | Harmful side effects | | 24,2, 40,39 | 3,33, 26 | 4,17, 34,26 | | | | | | | 19,1, 31 | 2,21, 27,1 | 2 | 22,35, 18,39 |
| 32 | Manufacturability | | | 1,35, 12,18 | | 24,2 | | | 2,5, 13,16 | 35,1, 11,9 | 2,13, 15 | 27,26, 1 | 6,28, 11,1 | 8,28, 1 | 35,1, 10,28 |
| 33 | Convenience of use | | 17,27, 8,40 | 25,13, 2,34 | 1,32, 35,23 | 2,25, 28,39 | | 2,5, 12 | | 12,26, 1,32 | 15,34, 1,16 | 32,26, 12,17 | | 1,34, 12,3 | 15,1, 28 |
| 34 | Repairability | | 11,10, 1,16 | 10,2, 13 | 25,10 | 35,10, 2,16 | | 1,35, 11,10 | 1,12, 26,15 | | 7,1, 4,16 | 35,1, 13,11 | | 34,35, 7,13 | 1,32, 10 |
| 35 | Adaptability | | 35,13, 8,24 | 35,5, 1,10 | | 35,11, 32,31 | | 1,13, 31 | 15,34, 1,16 | 1,16, 7,4 | | 15,29, 37,28 | 1 | 27,34, 35 | 35,28, 6,37 |
| 36 | Complexity of device | | 13,35, 1 | 2,26, 10,34 | 26,24, 32 | 22,19, 29,40 | 19,1 | 27,26, 1,13 | 27,9, 26,24 | 1,13 | 29,15, 28,37 | | 15,10, 37,28 | 15,1, 24 | 12,17, 28 |
| 37 | Complexity of control | | 27,40, 28,8 | 26,24, 32,28 | | 22,19, 29,28 | 2,21 | 5,28, 11,29 | 2,5 | 12,26 | 1,15 | 15,10, 37,28 | | 34,21 | 35,18 |
| 38 | Level of automation | | 11,27, 32 | 28,26, 10,34 | 28,26, 18,23 | 2,33 | 2 | 1,26, 13 | 1,12, 34,3 | 1,35, 13 | 27,4, 1,35 | 15,24, 10 | 34,27, 25 | | 5,12, 35,26 |
| 39 | Productivity | | 1,35, 10,38 | 1,10, 34,28 | 18,10, 32,1 | 22,35, 13,24 | 32,22, 18,39 | 35,28, 2,24 | 1,28, 7,19 | 1,32, 10,25 | 1,35, 28,37 | 12,17, 28,24 | 35,18, 27,2 | 5,12, 35,26 | |

Appendix III
Parameters of the Business Contradiction Matrix

Note this is copied from Mann.[17]

1. R&D Spec/Capability/Means
2. R&D Cost
3. R&D Time
4. R&D Risk
5. R&D Interfaces
6. Production Spec/Capability/Means
7. Production Cost
8. Production Time
9. Production Risk
10. Production Interfaces
11. Supply Spec/Capability/Means
12. Supply Cost
13. Supply Time
14. Supply Risk
15. Supply Interface
16. Product Reliability
17. Support Cost
18. Support Time
19. Support Risk
20. Support Interfaces
21. Customer revenue/Demand/Feedback
22. Amount of Information
23. Communication Flow
24. System affected harmful effects
25. System generated side effects
26. Convenience
27. Adaptability/Versatility
28. System Complexity
29. Control Complexity
30. Tension/Stress
31. Stability

Appendix IV
Vita

Frank Heinsohn was born in Charleston, S.C., on September 12, 1965. He grew up on Folly Beach, S.C. Folly Beach is also known as the Edge of America. Maybe there he looked out on the sea and became more open to concepts from foreign lands including TRIZ discussed in this thesis. Frank went to Porter-Gaud School for twelve years, graduated, and then attended Clemson University earning a Bachelor of Science Degree Magna Cum Laude with departmental honors in Mechanical Engineering.

Upon graduation Frank went to work at Westvaco Corporation in North Charleston, S.C., where he was a Process Engineer and Senior Process Engineer in the Pulp Mill and on a Paper Machine. After nine years in these positions, he became a liaison between the customers and Westvaco as a Technical Sales Service Engineer. His territory included the Midwest, Pacific Northwest, Taiwan, Hong Kong and China. After three years in this position, Frank changed companies and became a Senior Customer Focus Engineer with Corning, Inc., in the High Purity Fused Silica Group of Specialty Materials. This group provided lens blanks to the microlithography market. In 2003, Frank left Charleston for Bath County, Virginia to work for a material science solutions provider, MicroPhase Coatings, Inc. He started as Program Manager of Government Contracts. In April of 2004, he was promoted to V.P. and Chief Operating Officer, the position he currently holds.

He is the husband of Joan and father of dalas, Stacey, and Sophie.

END OF
TITLE