Trajectories of Technical Innovation Evolution: A TRIZ Exploration

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A Master's Thesis Submitted to Ritsumeikan Asia Pacific University In Partial Fulfillment of the Requirements for the Degree of Masters of Business Administration

May 2017

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Certification

I, PICKAR, PETER J. (ID: 52115627) hereby declare that the contents of this Master's Thesis are original and true, and have not been submitted at any other university or educational institution for the award of degree or diploma.
All the information derived from other published or unpublished sources has been cited and acknowledged appropriately.

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2017/05/31

Acknowledgements

To all those who have helped me reach this point,
and made this possible – I am forever grateful.
-PJP-

Summary

As of late, innovation has largely been driven by trial and error, experience and dictated by market needs through the traditional product development process[1] (PDP). The PDP is inherently the least understood and poorly managed methodology to innovation as it relies on enumeration of possibilities, resulting in loss of time, resources and competitive advantage (Fey & Rivin, 2007). To innovate on a more efficient level, a standardized approach, based on structured laws and algorithms is necessary to assess innovation and identify winning technologies that have contributed to technical evolution. Moreover, knowledge of these innovations through structured laws can contribute to the anticipation of the most likely step that the evolution of a technology will take (Fey & Rivin, 2007), thus allowing managers to predict the direction of a technology. TRIZ is such a methodology – developed by Genrich Altshuller in 1946, in the USSR, as a tool for "subtle, audacious and highly organized thinking operations" (Orloff, 2012). TRIZ states that the evolution of technology is not random, but follows a set of repeatable patterns and laws, which can be applied to the systemic development of technologies in both design and production.

TRIZ does not deal with pure physics or mathematics, but rather with inherent innovative models and inventive algorithms, thus allowing it to be applied to any problem – technological or not. While the heart of TRIZ is based upon conflict identification and resolution, modern TRIZ is based upon 4 innovative paradigms (Orloff, 2012):

[1] Need > problem definition > concept development > concept verification > detailed design > production.

1. *The "Artifact" paradigm* – examines the change of any object from its "initial" state to its "improved" state by identifying initial system contradictions and the resolution of these contradictions in the resulting state.
2. *The "Extracting" paradigm* – method to identify models of transformation in the resulting contradiction according to TRIZ methodology.
3. *The "Reinventing" paradigm* – modeling the complete cycle of creation for an invention as it has transformed over the ages to its present "final" state.
4. *The "Meta-Algorithm of Invention TRIZ" paradigm* – the summation of the 4 stages of ARIZ (Algorithm of Inventive Problem Solving) and the resulting idea generation of future technologies.

The research and application of modern TRIZ to all branches of business and technology is desirable to expose strategic solutions, improve existing technologies and contribute to the identification of successful technologies and their management. The aim of this thesis is to assess the effectiveness and importance of extracting technical evolution of a system in regards to projecting future trends of systems in accordance to the laws and tools of TRIZ. To test the aforementioned premise, a case study centered on the technical evolution of the lawnmower is performed.

Results of this research based case study yielded comprehensive solutions to nine key subsystems of the lawnmower and were carried out through two analyses. These results can be seen in the table below and highlight the key transformation models that most influenced technical innovation of lawnmowers. Accordingly, these principles were extracted from the technical evolution analysis and the Contradiction Matrix forecast which represent the transformation models that most influenced innovation and which most likely will influence innovation of next generation lawnmowers. These transformation models are key drivers of innovation according to the TRIZ methodology and can generate increased competitive positions.

Subsystem	*(Analysis I)* **TRIZ Transformation Model No.'s That Most Influenced Technical Innovation (EXTRACTED METHOD)**			*(Analysis II)* **TRIZ Transformation Model No.'s That Will Most Likely Influence Future Innovation (CONTRADICTION MATRIX FORECASTING.)**			
Mechanics and Mechanical Power	20	3	23	1	28	7	10
Cutting Level Control	15	3	14	27	35	10	34
Transmissions	24	15		10	4	29	15
Cutting Area	3	16		15	17	30	26
Discharge and Collection	24	3	22	10	6	2	34
Cutting Technology and Blades	3	6	17	2	27	35	40
Steering and Control	14	3	--	2	13	15	25
Drive-trains	20	24	--	28	10	--	--
Decks	40	14	--	1	8	15	40

General business application of utilizing the TRIZ methodology in this fashion can result in a deeper understanding of key innovative trends that have helped shape present dominate designs in products, as well as identify key drivers of innovation in any sector. This in turn can more accurately help managers determine future trends of products, allowing them to more effectively allocate funds and resources. The benefits and disadvantages of utilizing TRIZ transformation models to evaluate the technological evolution of a product, as well as projecting future trends of systems can be seen in the table below.

Benefits	Disadvantages
• Identification of future innovation trends • Revelation of key transformation models that have most influenced technical innovation of a product • Drastically narrows down which subsystems can combined, eliminated or improved at minimal effort • Provides a short-to-mid-range picture of the next steps a technology will take • Provides key tools to solve innovation complications • Structured methodology lending its application to lifetime or future of product • Applicable to any technological system • Further TRIZ tools can be applied	• Time consuming – often with the data being overwhelming • Need compressive knowledge of the system and access to its technical development history to provide a complete picture of its technical development and identify key transformation models • Not often clear which transformation models should be used • Narrows down trajectory of technical evolution but a strong background in engineering is still needed when assessing technical systems • Does not provide a clear picture of long-term technical development • Results may vary with different

to this method to create a stronger prediction of future trends • This methodology of technical extraction is strong at providing an general overview of the system and its subsystems technical evolution and general direction of future trends • Methodology repeatable for other industries	people • Strong TRIZ background needed to fully utilize the methodology • The use of different TRIZ tools are needed to pinpoint clear solutions to very direct innovative problems • Defining correct TRIZ system conflict is paramount to arriving at correct TRIZ solution

Chapter 1 - Introduction

1.1. Introduction

The traditional product development process (PDP) has long been heralded as a successful means to innovation. Yet innovations produced by this process are largely shaped by trial and error, internal experience and arbitrary steps that largely result in simple incremental improvements to a product - not true innovation. This has led to the loss of competitive advantages and failure of numerous well-known firms because valuable time and resources were wasted through the inability of management to predict and plan for future technologies. Firms in this day and age need to be able to produce innovative products that best utilize their resources, provide higher value to consumers and reduce design cycle times to maximize success.

To innovate on a more efficient level, a standardized approach to innovation based on structured laws and algorithms is necessary to identify future winning technologies and trends. By doing so, industries can best focus their resources on applying proven principles that more accurately track the course and evolution of future products.

One of the most prominent methodologies to standardized innovation is the Russian Theory of Innovative Problem Solving, commonly known as TRIZ. TRIZ consists of a host of tools and principles aimed at breaking the uncertainty in identifying the future direction of innovations and providing breakthrough concepts to seemingly impassable conflicts to advance innovation in a clear and standardized fashion.

To best understand and test the confines of TRIZ, this paper aims to evaluate the importance TRIZ transformation models play in the technological evolution of a product, as well in projecting future trends of systems. Identification of TRIZ transformation models is key to understanding which principles produced the greatest innovative progress throughout the system's (product's) technical evolution, as well as laying the groundwork for predicting future developments.

In order to produce an evaluation describing the importance TRIZ transformation models and technical evolution play in innovation, the use of a case study will be performed to provide insight into TRIZ and innovation as a whole. The case study will be centered around the technical evolution of the push lawnmower, breaking down and identifying the key innovative steps that have resulted in modern day dominant designs[2] according to TRIZ transformation models. Identification of these transformation models is fundamental to support which principles produced the greatest innovative progress overall and in each subsystem of the lawnmower, thereby producing a standardized list of the most effective TRIZ transformation model principles. Subsequently, this list should outline key principles that can be used as a guide to further innovative progress in each subsystem and as a whole.

Once the dominant-design of lawnmowers has been reached and the technical evolution extracted, the use of the TRIZ contradiction matrix will be used to explore short-term problem solutions to immediate innovation impasses. Since these principles are standardized, they can offer a structured approach for future technical developments and effectively be transferred to other area of innovation.

The findings of this study can significantly aid in the advancement of

[2] Dominant design: The main design of a product that firms and innovators must achieve to win market acceptance.

innovation technologies, as well as provide a foundation for future innovation techniques. As this research is based on a standardized method of innovation and utilizes an empirical case study, the findings can be related to innovation as a whole in any industry.

1.2. Structure of Thesis

The structure of this thesis is formatted to provide a step-by-step approach to introducing the TRIZ method of systematic innovation by first presenting an in-depth literature review. The literature review aims to provide the reader with significant background to understand the use of TRIZ in this research, and as a guide for future analysis.

Following the literature review, the research methods, questions and methodology used will be stated. Subsequently, the case study analysis of the push lawnmower will be explored by extracting technical innovations that evolved the mower to its present day designs. Once the evolution of technical innovation has been established, the TRIZ contradiction matrix will be utilized to perform an analysis of future trends the push mower will likely incorporate. The recommendations will follow the analysis, closing with the conclusion to the overall research objectives.

Chapter 2 - Literature Review

2.1. Introduction – The Traditional Product Development Process

Innovation, as defined by the Merriam Webster dictionary is the act of introducing something new - be it an idea, a method or device. Until recently, innovation has been driven by the enumeration of possibilities (Orloff, 2012), chiefly produced by the trial and error method and defined by haphazard steps (Fey & Rivin, 2007), resulting in staggered innovation and technological evolutions. These haphazard steps and enumeration of possibilities are the result of the modern product development process (PDP) that relies on the individual(s) or engineer(s) creativity and collective experiences. The traditional product development process follows 5 stages, which can be seen below in (figure 2-1), starting with the identification of a need and ending with a detailed design.

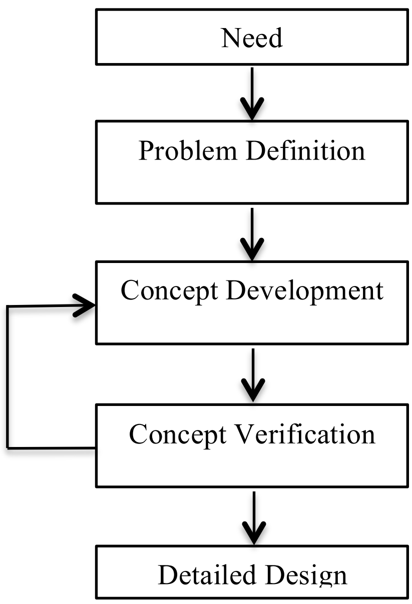


Figure 2-1: The traditional product development process (PDP)
Source: (Fey & Rivin, 2007)

In the first step, the identification of a need or area of deficiency is established with the overall goal of "understanding customers' needs and effectively communicating them to the development team" (Ulrich & Eppinger, 2012). The output of this step is a clearly defined problem statement, in which a list of various constraints are then defined such as performance, manufacturing limitations, restrictions, etc. In other words, the problem definition phase translates the "need" into technical terms with precise descriptions of what the product has to accomplish.

Following is the concept development stage, where a mix of external and internal searches, creative problems solving, and systematic exploration (Ulrich & Eppinger, 2012) are used to generate a wide array of concepts. This is most likely performed through the five-step concept generation method, which can be seen below in (figure 2-2).

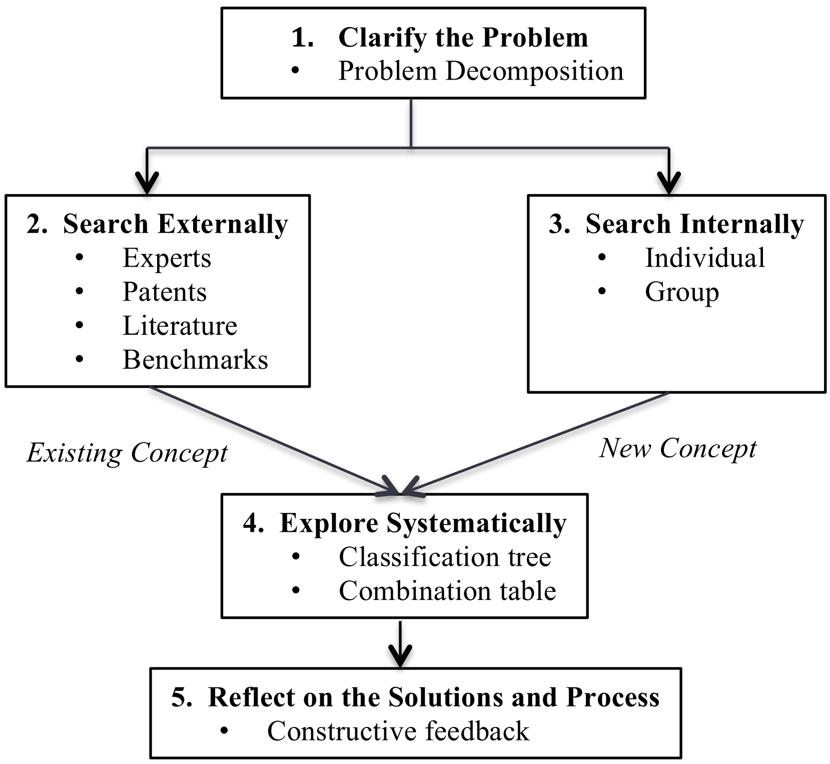


Figure 2-2: Five-step concept generation process of the concept development stage
Source: (Ulrich & Eppinger, 2012)

Subsequently, this method results in stochastic idea generation and it is within this step that the "flow of ideas is uncontrollable, and attempts (trials) are repeated as many times as needed to find a solution" (Fey & Rivin, 2007). These haphazardly acquired and different ideas are then evaluated against the original problem definition with the best one being selected to move onto the concept verification stage.

In the concept verification stage a prototype is typically created and tested to "identify any shortcomings that must be remedied" (Ulrich & Eppinger, 2012). Once all constraints and shortcomings are either eliminated or minimized, the concept is moved to the final stage – the detailed design stage, where the design is fully developed and detailed drawings are then produced.

2.2. Pitfalls of the Product Development Process

Innovation leading to technical evolution is hard, as can be witnessed by our staggered history of technical inventions – it was only a century ago that humans were first able to take to the sky in airplanes. Few companies and individuals are successful at it because it relies on the limited retrospective knowledge of the users. Even with the application of the modern product development process and simulation tools such as CAD programs, "creation is still regarded as a basically random process which is ultimately reduced to enumeration of possibilities and brainstorming" (Orloff, 2012). This results in "valuable time being wasted when searching for solutions to difficult problems" (Fey & Rivin, 2007) as well as loss of competitiveness and the inability of management to predict the direction of future technologies. Furthermore, according to Ulrich and Eppinger authors of *Product*

Design and Development, challenges and failures of using the PDP process include (Ulrich & Eppinger, 2012):

- ***Trade-offs***: Selecting and managing the inherent benefits and drawbacks a technical innovation will provide to maximize the success or useful function of the product.
- ***Dynamics***: As technologies improve and customer preferences evolve, selecting the direction of future technologies is increasingly challenging.
- ***Details***: Developing products with minimal complexity to maximize their main useful function and eliminate un-needed parts.
- ***Time pressure***: The PDP inherently consumes a large amount of time due to the chaotic nature of trial and error to single in on a winning design.
- ***Economics***: To produce a winning design, the end product must be appealing and economical to produce.

As gathered from above, the main pitfalls of the product development process lay in the first two major phases of development – [1] identification of a need and [2] concept development (Fey & Rivin, 2007). In the first stage and drawback, identification of a need is paramount to selecting an innovation strategy that will ultimately produce a winning technology from a highly defined problem definition. In other words, a strong understanding of technological evolution is needed to identify the direct area of deficiency and "conventional approaches to identification of next-generation winning products and technologies cannot provide a reliable answer to these questions" (Fey & Rivin, 2007). Consequently, identification of the wrong need can lead to loss of competitiveness, resources and manpower as firms choose to develop the wrong product.

The second and largest pitfall of the product development process is the concept development stage, as it lacks a structured innovation process consequently resulting in an arbitrary set of solutions that are derived from the inventor(s) set of experiences and knowledge. It is here that "the most important decisions are made which bring together engineering, production, and commercial aspects of the problem" (Fey & Rivin, 2007), and it is here that the old paradigm of innovation, that "the creative process cannot be managed" (Orloff, 2012) fully takes its toll. This is because idea generation is random - stochastic at best, and where good ideas are often discarded because the inventors lack a structured framework to systematic innovation. Even the most prominent researchers of innovation methods, Karl T. Ulrich and Steven D. Eppinger, from the Wharton School of business and Massachusetts Institute of technology note that:

> "Although the concept generation is an inherently creative process, teams can benefit from using a structured method. Such an approach allows full exploration of the design space and reduces the chance of oversight in the types of solution concepts considered. It also acts as a map for those team members who are less experienced in design problem solving." (Ulrich & Eppinger, 2012)

The addition of a structured and standardized method to innovation has long been necessary to innovate on a higher level that is well managed, structured and efficient. As the boundaries of what is feasible and what is not becomes better understood, a method that "allows us to select the most promising concept… with fewer resources, at the lowest cost with higher quality and with shorter design cycle times" (Fey &

Rivin, 2007) has long been necessary. More importantly, the need to advance to a new innovative process that guides the thinking process, with minimum expenditure of resources, and useable by all is essential to developing new technologies and redefining the product development process.

2.3. Moving to a Systematic Approach to Innovation

The belief that the creative process cannot be managed has impeded innovation in every sector and led to the failure of some of the largest firms throughout our history. This has largely been due to the old paradigm of thinking, in which "creation is regarded as a basically random process which is ultimately reduced to enumeration of possibilities and brainstorming" (Orloff, 2012). This resilient mindset has shielded us from a myriad of innovative solutions that have for centuries been in front of our eyes. Genrich Altshuller was the first to realize that "technical problems could be solved by utilizing principles previously used to solve similar problems in other inventive situations" (Altshuller G. , 2002) through study and comparison of thousands of prominent patents. In other words, Altshuller discovered that the evolution of technical systems over a period of time followed a set of repeatable patterns and laws, which then would dictate the most likely next step a technology would take.

The identification and classification of these patterns laid the foundation of the TRIZ approach. TRIZ stands for the *Theory of Innovative Problem Solving* or in Russian, ***T****eoriya* ***R****esheniya* ***I****zobretatelskikh* ***Z****adach* and reflects Altshuller's original aim of deriving a new structured method to the innovation process. The TRIZ method is designed to be systematic in nature as it obeys the following conditions (Chen & Liou, 2011):

1. Is systematic in nature – follows a step by step procedure
2. Is a guide that directs to the best solution
3. Is repeatable and reliable; does not rely on psychosocial instincts
4. Is able to utilize mankind's vast accumulation of knowledge
5. Is able to contribute to mankind's body of knowledge
6. Is usable by innovators, by following a general approach

At the heart of Altshuller's theory was the discovery that "any part of a system having already reached its pinnacle of functional performance will lead to conflict with another part" (Altshuller G. , 2002). Classification of these conflicts led to the formation of the nine laws (table 2-1) that govern technical evolution and "delineate the prevailing trends of the evolution of technological systems" (Fey & Rivin, 2007). Laws 1 to 4 govern technical systems evolution at all stages, while laws 5 to 9 can be applied to any system, technical or not. Violations of these laws are rare. TRIZ does not deal with mechanisms, machines and processes (Fey & Rivin, 2007), but rather with their models allowing the TRIZ method to be applied to any problem, technological or not, in a systematic fashion.

Laws of Technical Evolution	
1.	Law of increasing degree of ideality
2.	Law of non-uniform evolution of subsystems
3.	Law of transition to a higher-level system
4.	Law of transition to a higher-level system
5.	Law of increasing dynamism (flexibility)
6.	Law of transition to micro-level

7.	Law of completeness
8.	Law of shortening of energy flow path
9.	Law of shortening of energy flow path

Table 2-1: Laws of Technical Evolution
Source: (Fey & Rivin, 2007)

The premise of TRIZ and systematic innovation does not remove the thinking and creative process, but rather "it simply guides the thinking process, protects from mistakes, and forces the user to perform unusual – talented thinking operations" (Altshuller G. S., 1979). This first and foremost helps the user clearly identify the problem to be solved, then points the user in the direction of solutions that have solved similar types of problems in the past. Instead of randomly guessing at solutions, "TRIZ uses cogitative activities which rely on knowing the laws governing evolution of technical systems… [thus] the creative universe becomes infinitely manageable and, therefore can be infinitely expanded" (Orloff, 2012). Equally, TRIZ requires "something to happen or a problem needs to be solved before a problem solving process can be carried on" (Chen & Liou, 2011) lending a structured and systematic approach to problem solving. Hence forth, the application of TRIZ to innovative problems elevates the creative process and potential of all individuals to create, invent, design and discover – a process once thought only to be harnessed by talented and ingenious individuals.

2.4. Introduction to TRIZ

Over the past 70 years since the creation of TRIZ by Altshuller, the TRIZ method has evolved to encompass a set of principles and tools, used for innovation and problem solving. The bases of these tools rely on the definition of a system. A *system* can be defined as any entity that is made up of interacting parts (subsystems) and responds to a hierarchy, defining each of its subsystems. This means that TRIZ can be used in any system (i.e. biological, societal, business, technical, medical, bureaucratic, etc.), although it is primarily geared for technical systems.

A *technical system* is defined as any system that is designed to perform a function. A *function* is the intended useful action of the system. Examples of technical systems include everything around you (i.e. bottle, chair, bicycle, cellphone, car, etc.) and consist of one or more subsystems, each performing its own function. Because technical systems are designed in hierarchies, the "properties of each subsystem are influenced by the properties of the higher- and lower-level systems" (Fey & Rivin, 2007), "from the least complex, with only two elements to the most complex with many interacting elements" (Altshuller G. , 2002). This means that the smallest subsystem can have an effect on the overall technical system and its performance. Likewise, changes in any one subsystem can have beneficial or adverse effects in higher subsystems (Altshuller G. , 2002). This is a central point as technical systems evolve at different rates, subsequently imposing inadequate or harmful function on the overall system, as one system advances or lags to the other. This is what is known as a *system contradiction/conflict*, where an inventive problem occurs. Resolution of a system contradiction results in innovation and technical evolution of a system.

2.5. Foundation of TRIZ

TRIZ like any theory is based upon a set of postulates, which create the foundation of theory. The TRIZ method relies on three branches (Cascini, 2012):

1. *Existence of Objective Laws of Engineering System Evolution*: Technical systems evolve following a set of repeatable patterns, which are governed by the Laws of Technical Evolution. Every system moves toward ideality over a period of time.

2. *Contradictions*: As systems evolve, conflicts between a system and its environment or between the systems in its hierarchy impede innovation. Resolution of these conflicts is necessary to forward innovation.

3. *Specific Situation and Resources*: The evolution of a system occurs in given environment, which influences the innovation process and controls what resources are used to overcome the contradiction. Before any additional resources are added to the system, all present resources are maximized to maintain ideality and simplicity.

At the core of TRIZ is the identification of system contradictions and the notion all systems move toward ideality. Ideality is the first law of technical innovation and states, "any technical system throughout its lifetime, tends to become more reliable, simple and effective" (Altshuller G. , 2002). Thus, every time a system improves, it becomes more ideal – a state which reflects the maximum utilization of resources. When a system reaches its ideal state, the "mechanism disappears, while the function is performed" (Altshuller G. , 2002). On the other hand, when a technical system ceases to perform to specifications or requirements, it needs to be improved. TRIZ contains a host of different methods and tools to help solve difficult technical system problems as well as to extract innovative principles used to evolve a system. These tools take into account the (Moehrle, 2005):

- Current State – what is the existing state of the system?
- Resources – what resources are available?
- Goals – what is the need of the system?
- Intended State – what should the future state of the system achieve?
- Transformation – how can the present system transform to the intended state?

To properly address the different tools used to identify, solve, project and extract technical evolution, the following sections will be devoted to some of the key methods, principles and tools of TRIZ.

2.6. Functions, Actions and System Contradiction Diagrams

A function, as described above, is the useful action performed by the system – "it is the motivation for its [the systems] existence" (Cascini, 2012). In TRIZ, a function always involves two components: [1] an object and [2] a tool. In a function, the object is the part that requires control (i.e. to me moved, measured, detected, etc.). Alone, an object cannot control itself and requires a tool. In order for the tool to preform a useful operation, an action performed by the tool is implemented on the object. The act of implementing the tools action on the object is known as a function and can be modeled as follows:

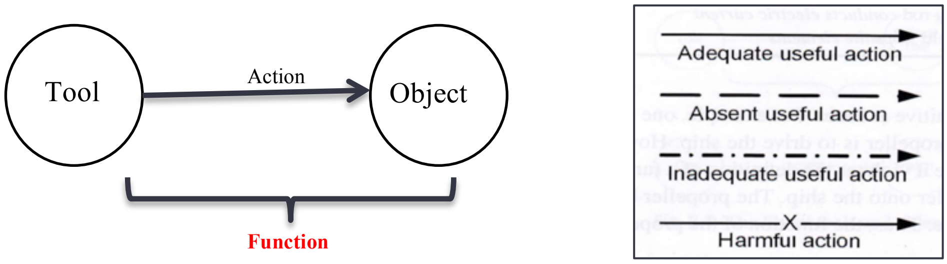


Figure 2-3: Model of a Function and Action Types
Source: (Fey & Rivin, 2007)

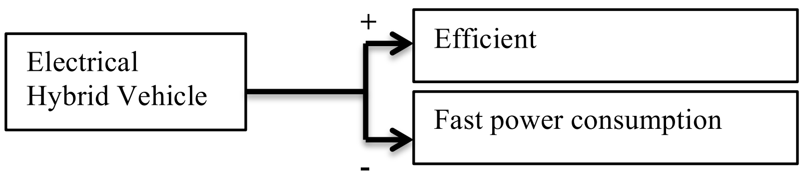
Different tools can be implemented to perform the same action on the object, but not all actions are equal. TRIZ takes into account four different types of actions as can be seen above in (figure 2-3). Adequate useful actions should be emphasized while harmful actions should be removed from a function. Functions can be modeled into a chain where the *primary function* (PF) is the resulting main purpose of the technological system. Each underlying subsystem is known as an *auxiliary function* (AF). In a technological system, a set of different functions will inherently bring about a system conflict.

System conflicts are present when a useful action simultaneously causes a harmful effect, or the removal of a harmful action results in undesired performance (Fey & Rivin, 2007). According to Altshuller, the most effective solutions to innovative problems are achieved when the system conflict is fully resolved. As discussed above, functions are used to explain the characteristics or parameters of a technical system, and "help determine the technical contradictions residing in the problem" (Altshuller G. , 2002). Owing to this fact, it is recommended that "problem solving should start with the identification of the contradictions limiting the ideality of a technical system" (Cascini, 2012). In other words, the root cause inhibiting the technical evolution should be addressed first.

According to TRIZ, system contradictions (SC) can form two types of conflicts: [1] *standard contradiction/technical contradiction* and [2] *radical contradiction/physical contradiction* (Burz & Marian, 2011) (Orloff, 2012). A *standard contradiction* represents two factors "where one factor requires improvement, while the other factor either deteriorates concurrently with improvement of the first factor, or hinders such improvement" (Orloff, 2012). The system contradiction reflects two factors of the object – the factor that is improving and the factor that is detracting or counteracting the improving factor. System contradictions can be modeled three different ways, by text, formula or by graphical model. Lets take an electrical hybrid vehicle as an example to illustrate a standard contradiction.

- **Text:** An electrical hybrid vehicle is efficient but uses battery power quickly and cannot travel far.
- **Formula:** Electrical hybrid vehicle > efficient vs. fast power consumption

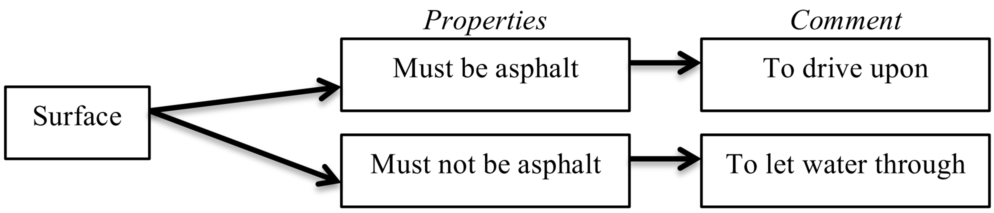
  (*Note: The symbol > represents a contradiction)
- **Graphical Model (standard technical contradiction):**



The second type of contradiction, the *radical contradiction* is present when two factors require contradictory states from the same object resulting in incompatibility (Orloff, 2012). For example, something *must be* big, but at the same *must be* small, or something *must be* hard and soft – two incompatible properties. An example of this would be the invention of pervious asphalt[3]. Before the invention of pervious asphalt, when it rained, water would puddle up on the top of the asphalt making driving and walking difficult. The radical contradiction can be modeled in the same three ways as the standard contradiction and can be seen below.

- **Text:** The radical contradiction in this problem is the asphalt must be present to drive upon and it must not be present when it rains so the rainwater can drain into the ground.
- **Formula:** Surface > must be asphalt : must not be asphalt

  (*Note: The symbol > represents a contradiction)
- **Graphical Model (radical physical contradiction):**



Standard and radical contradictions can be present in the same system or innovative problem. Identifying the correct system conflict and the resulting contradictions are paramount to identifying the right solution. "The key to solving problems lies in a more detailed definition of contradictions inherent in the original problem situation" (Orloff, 2012) and can be achieved with the use of graphical modeling to help identify the root cause through the primary function of the system.

[3] See: http://www.asphaltpavement.org

2.7. 40 Innovative Principles, the Contradiction Matrix and Separation Principles of TRIZ

As clarified, system contradiction identification is the core of TRIZ and properly identifying them and resolving them results in a self-sustaining process until the system reaches its ideal state (Fey & Rivin, 2007). Traditionally, as innovators cross a contradiction they seek to adopt a compromise or trade-off, which does not eliminate the system conflict but rather softens them (Orloff, 2012) (Hsieh & Chen, 2010). This is not considered an innovative solution according to TRIZ, as it does nothing to evolve the system; rather it just prolongs it by dampening the harmful function. By definition, an inventive problem must contain at least "one contradiction and the inventive solution identified must eliminate the contradiction to improve performance" (Blackburn, Mazzuchi, & Sarkani, 2012).

Altshuller based TRIZ on contradiction resolution and after a study of over 200,000 patents in which he "recognized that the same fundamental problems (contradictions) in one area had been addressed by many inventors in other technological areas" (Petkovic, Issa, Palvoic, & Zentner, 2013). From this discovery, Altshuller concluded that there are only 39 standard technical features that can lead to system conflict and are called the *Technical* (*Engineering) Parameters* (Burz & Marian, 2011). The 39 Technical Parameters can be seen below in (table 2-2) and can be used in any engineering discipline.

39 Technical Parameters of TRIZ			
No.	**Name**	**No.**	**Name**
1.	Weight of moving object	21.	Power
2.	Weight of stationary object	22.	Waste or loss of energy
3.	Length of moving object	23.	Waste or loss of substance
4.	Length of stationary object	24.	Loss of information
5.	Area of moving object	25.	Waste or loss of time
6.	Area of stationary object	26.	Quantity/Amount of substance
7.	Volume of moving object	27.	Reliability
8.	Volume of stationary object	28.	Measurement accuracy
9.	Speed	29.	Manufacturing precision
10.	Force (intensity)	30.	Harmful factors acting on the object
11.	Tension, Pressure	31.	Harmful side effects (generated by object)
12.	Shape	32.	Ease of manufacture
13.	Stability of the object	33.	Ease of operation
14.	Strength	34.	Ease of repair
15.	Durability of moving object / Duration of action	35.	Adaptability or versatility
16.	Durability of stationary object / Duration of action	36.	Complexity of device
17.	Temperature	37.	Complexity of control
18.	Brightness (illumination intensity)	38.	Level of automation
19.	Use of energy by moving object	39.	Productivity
20.	Use of energy by stationary object		

Table 2-2: 39 Technical Parameters of TRIZ
Source: (Altshuller G. , 2002) (Petkovic, Issa, Palvoic, & Zentner, 2013) (Blackburn, Mazzuchi, & Sarkani, 2012)

As stated in TRIZ, there are only two types of contradictions, [1] Standard Technical Contradictions and [2] Radical Physical Contradictions. Standard technical contradictions cause a compromise where one parameter is worsening while the other is becoming better (Burz & Marian, 2011). To solve for standard technical contradictions, Altshuller identified 40 principles in "which most technical contradictions may be resolved" (Burz & Marian, 2011). These 40 principles are used to overcome technical contradictions and are *the main tool of TRIZ*, which "allow the development of numerous solution concepts for every technical problem – without introducing a compromise," (Altshuller G. , 2002). These 40 Principles only in name are listed below in (Table 2-3). These principles are also known as *transformation models* as they can be used to describe the technical evolutionary process of an artifact.

40 Principles to Innovation - Transformation Models			
No.	**Name**	**No.**	**Name**
1.	Segmentation	21.	Rushing Through
2.	Extraction	22.	Convert Harm into Benefit
3.	Local Quality	23.	Feedback
4.	Asymmetry	24.	Mediator
5.	Consolidation	25.	Self Service
6.	Universality	26.	Copying
7.	Nesting (Matrioshka)	27.	Dispose
8.	Counterweight	28.	Replacement of Mechanical System
9.	Prior Counteraction	29.	Pneumatic or Hydraulic Construction
10.	Prior Action	30.	Flexible Films or Thin Membranes
11.	Cushion in Advance	31.	Porous Materials
12.	Equipotentiality	32.	Changing the Color
13.	Do it in Reverse	33.	Homogeneity
14.	Spheroidality	34.	Rejecting and Regenerating Parts
15.	Dynamicity	35.	Transformation Properties
16.	Partial or Excessive Action	36.	Phase Transition
17.	Transition Into a New Dimension	37.	Thermal Expansion
18.	Mechanical Vibration	38.	Accelerated Oxidation
19.	Periodic Action	39.	Inert Environment
20.	Continuity of Useful Action	40.	Composite Materials

Table 2-3: 40 Principles to Innovation
Source: (Altshuller G. , 2002)

From these 40 Principles in which most technical contradictions can be solved, Altshuller derived the *Contradictions Matrix*. The contradiction matrix, utilizes the 39 technical parameters in conjunction with the 40 Principles to arrive at frequently used solutions for technical contradictions (Hsieh & Chen, 2010), which involve a improving parameter and a worsening parameter. This allows for the "connection of abstract problems with abstract solutions [inventive principles]" (Moehrle, 2005). It is necessary to point out that the use of the contradiction matrix does not replace creativity; rather it guides the user to arrive at solution, which has been known to eliminate the problematic contradiction and resolve the technical contradiction.

To use the contradiction matrix, first the technical contradiction should be modeled clearly stating the parameter that is improving and the one that is worsening. On the contradiction matrix table, the parameter that is improving is identified in the vertical column of 39 characteristics to be improved. The parameter that is worsening is identified on the top horizontal rows of 39 characteristics that is getting worse. Where the two intersect are numbers representing the 40 Principles. These numbers "refer to the inventive principles that have been most frequently used to resolve this the conflict" (Chen & Liou, 2011). Altshuller notes, that "when working with the Principles, and the Matrix, remember that the suggested principles can generate the most promising concepts for resolving a technical contradiction" (Altshuller G. , 2002). Occasionally, the suggested principle(s) result in a secondary problem. In this case, Altshuller recommends not to automatically reject it, but rather to solve the secondary problem first.

To solve for the second type of contradiction, [2] radical physical contradictions, TRIZ identifies three principles of separation. Recall that radical contradiction requires "two opposite contradictory properties that are requested from the same component of a technical system" (Burz & Marian, 2011). The *separation principles* are as follows (Fey & Rivin, 2007):

1. *Separation of opposite properties in time* – At one time a component has property (P) and at another it has the opposite property (-P).
2. *Separation of opposite properties in space* – One part of a component has property (P) while the other has the opposite property (-P).
3. *Separation of opposite properties between the whole and its parts* – A system has property (P), while its components have property (-P).

While these separation properties are ambiguous in nature, in practice they become much more clear. The main goal of the separation principles is to detach the contradictory properties from the same component through use of the three methods above. One of the main principles used to resolve such contradiction is the use of the Law of Increasing Dynamism (flexibility). This allows for the separation of the components contradictory properties and use of such principles as segmentation, asymmetry, universality, etc. from the 40 principles.

2.8. Modern TRIZ

Because TRIZ is relatively new, and its application limitless, the TRIZ model is continuously expanding and developing new methods and techniques based on the nine laws of technical system evolution. Over the past 70 years since the creation of TRIZ by Altshuller, the TRIZ approach has evolved to encompass a set of principles and tools, used for innovation and problem solving. Known as "contemporary or modern" TRIZ, modern TRIZ is composed of two sub-systems: [1] Tools for development of conceptual designs and [2] Tools for identification and development of next-generation technologies (Fey & Rivin, 2007), which are based upon the laws of technical system evolution. The structure of modern TRIZ can be seen below in (figure 2-12).

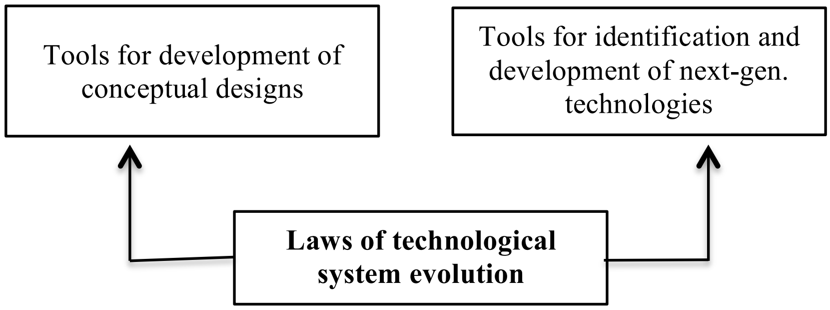


Figure 2-12: Structure of Modern TRIZ
Source: (Fey & Rivin, 2007)

Modern TRIZ does not deal with pure physics or mathematics, but rather with a systems inherent models and inventive algorithms, thus allowing it to be applied to any problem – technological or not. Modern TRIZ seeks to apply this principle to all systems and is based upon 4 innovative paradigms (Orloff, 2012):

1. *The "Artifact" paradigm* – examines the change of any object from its "initial" state to its "improved" state by identifying key system contradictions.
2. *The "Extracting" paradigm* – method to identify models of transformation and conflict resolution in the resulting artifact according to TRIZ methodology.
3. *The "Reinventing" paradigm* – modeling the complete cycle of creation for an invention as it has transformed over the ages to its present "final" state.
4. *The "Meta-Algorithm of Invention TRIZ" paradigm* – the summation of the 4 stages of ARIZ (Algorithm of Inventive Problem Solving) and the resulting idea generation of future technologies.

The strength in these paradigms lies in fact that the TRIZ method can be applied to pre-existing artifacts to extract transformation models and examine contradictions that have helped shape future iterations of the artifact. The extraction of these models is then useful in predicting trends that have help shaped the technical evolution of the artifact and can lead to identification of trends that future iterations of the artifact will have.

2.9. Management and TRIZ

Within any industry, it is imperative to address innovation from a management point of view. Innovation management "is one of the most important and complex issues an organization is faced with today" (Tohidi & Jabbari, 2012) and it directly influences the success of the firm in regards to its competitive advantages. This can easily be seen in the modern failures of companies such as Nokia, Kodak, Motorola and Polaroid (Thangavelu , 2015), which all failed to properly innovate and were crushed by firms that did.

Rapid technological advancements, globalization and the fast pace of today's markets are forcing industries to change the way they do business. Organizations "must make full use of its internal resources to engage in innovation and create values for customers and society as a whole if wanting to establish a particular competitive advantage" (Liu, Wu, & Hong, 2010). Properly managing these internal resources to drive competitive advantages or forecast, "technical advancements that will shape the future is circuital for many industries" (Barbulescu & Ionescu, 2010) allowing organizations benefits such as:

- Enhanced competitive position
- Discernment of overlooked strategic solutions
- Reduced R&D costs
- Optimal planning
- Optimal distribution of resources

The idea driving these principles is finding right balance of management that will properly identify winning technologies, allocate resources and deliver a product that exceeds its original need, with fewer assets and shorter time. The need for management to move away from conventional approaches such as the PDP and be able to utilize a systematic approach in resolving these issues has become the real key to success in competition (Chen & Liou, 2011).

In light of this, TRIZ should be a key tool of management as it has been proven to "generate breakthrough concepts and ideas, [resolve] conflicts, increase the reliability of technological forecasts of improvements over your competitors' products, and improve the appropriate decision to solve long-term planning" (Chen & Liou, 2011). This can be seen in the success of "top Fortune 500 companies such as Ford, GM, Chrysler, Exxon, Rockwell International, P&G, Digital Equipment, Xerox, HP, BAE Systems, Boeing, Philips Semiconductors, LG, Boston Scientific, Intel, Samsung, etc. that are successfully using the TRIZ methodology" (Burz & Marian, 2011). For these reasons and more, the application of TRIZ to management is imperative, as it allows managers to not only guide the direction of a technology, but even more so, the overall direction and strategy of the organization resulting in an enhanced competitive position.

Chapter 3 - Research Methods

3.1. General Concept

The traditional product development process has long been used to forward innovation to determine the next likely step evolution of a technology will take. This process has resulted in mismanagement of technology that has often resulted in overlooked strategic solutions that would otherwise enhance competitive advantages. This is because technological evolution takes time - with some of the simplest ideas taking decades to realize, formulate and implement. However small these innovations seem today, they are critical for the development of all technological systems - and if identified, will show technical evolutionary trends in their respective sectors.

The aim of this report is to utilize the TRIZ methodology of standardized innovation to assess the importance technical evolution of a system plays in projecting future trends, by drawing out its respective TRIZ system conflicts and transformation models. By doing so, these system conflicts and transformation models will illustrate the technical problems and resolutions that have advanced a system from its primitive form to its modern day dominant design[4] in a standardized fashion. Subsequently, identification of these system conflicts may uncover previously solved problems that can be applied to modern industry as well as laying the groundwork for the direction of future innovations.

To do this, a case study will be performed on a single consumer good, utilizing the TRIZ method to standardized technical extraction and identification of transformation

[4] Dominant design: The main design of a product that firms and innovators must achieve to win market acceptance.

models for each step of the system's evolution. The use of a case study is important to first test the feasibility of the method, but also to serve as a guideline to other industries. Thus the findings of this report aim to generate new insights into the dynamics of innovation through studying the technical evolution of a product using the TRIZ method. Moreover, the outcomes of this research can then be translated other industries, as well as to verify the strength and validity of TRIZ.

Major themes in the methodology of this research include:

- Orloff's paradigms to Modern TRIZ
- Identification of system conflicts
- TRIZ 39 Engineering Parameters
- TRIZ 40 Innovative Principles (Transformation Models)
- TRIZ Contradiction Matrix

3.2. Case Study Target Industry

The use of a case study is indented to demonstrate the feasibility of the TRIZ method and its adaptability to other areas of industry, as well as underline the general complexities encountered. In this research, the target of the case study is the lawn care industry - specifically the product of the push lawnmower. The decision to target this industry and consumer good was made due to the relatively short and accessible history of the lawn mower (187 years to date), as well as the mid-level of complexity of its technical systems. This abundant information and technicality of the lawn mower allow for a full evaluation of the TRIZ method as well as the results to be used in other areas of academia and industry.

3.3. Research Questions

This research aims to use the case study of the lawnmower as a demonstration to evaluate the importance the TRIZ standardized methodology to technical extraction and evolution play in innovation and projecting future trends of systems. In order to address this postulate, four key questions have been devised to examine the objective and feasibility of this research. These are:

1. What contradiction and transformation model resolutions have led to the present level of lawn mower technology?
2. Which TRIZ transformation models have had the greatest impact on the technical evolution of lawn mowers?
3. According to TRIZ, what is the next probable direction the lawn mower (care) industry will take?
4. By utilizing the TRIZ method to extract technical evolution, can a technical forecast be reasonably made?

3.4. Methodology

The methodology for this research will follow the TRIZ approach to extracting technical evolution. This report is designed to be understood and used by managers without an engineering background as it assess general traits of a technical system in accordance with the laws and tools of TRIZ.

To extract the technical evolution of lawnmowers, the research will start with the identification of the first invention of the lawnmower. From here, subsequent major technological advances will be identified until present day dominant designs are realized. The forecasting of technological systems will be based off modern dominant designs parameters and through identification of the key subsystems that comprise the lawnmower.

To extract technological innovation in a consistent fashion the TRIZ method to standardized innovation will be utilized. This report intends to use the four paradigms of modern TRIZ as the central methodology to extract technical evolution from a system in order to acquire understanding of evolutionary innovation trends that can impact potential developments as well as predict upcoming trends in technology. As stated in the literature review, Orloff's four paradigms are:

1. *The "Artifact" paradigm* – examines the change of any object from its "initial" state to its "improved" state by identifying key system contradictions.
2. *The "Extracting" paradigm* – method to identify models of transformation and conflict resolution in the resulting artifact according to TRIZ methodology.
3. *The "Reinventing" paradigm* – modeling the complete cycle of creation for an invention as it has transformed over the ages to its present "final" state.
4. *The "Meta-Algorithm of Invention TRIZ" paradigm* – the use of ARIZ (Algorithm of Inventive Problem Solving) TRIZ tools and the resulting idea generation of future technologies.

As stated, paradigms #1 to #3 encompass tools for technical evolution extraction and paradigm #4 is used for technological forecasting. The research of this report is divided into two analyses – the first for extracting technological evolution (paradigms #1-3) and the second, for defining technical forecasting (paradigm #4) in accordance to TRIZ.

3.5. Methodology Analysis I (Technological Evolution)

In the first analysis, paradigms #1 to #3 will be utilized to extract the technical evolution of the lawnmower. To more accurately identify specific technologies that led to innovation, the lawnmower will be separated into key subsystems that are universal from the first invention to modern dominant designs.

This analysis will begin by identifying the first invention of the lawnmower and its next subsequent "improved" state, through historical study and patent review to maintain authenticity. The improved state is the application of a technical advancement that resulted in an innovation. A comparison of the "initial state" to the "improved state" will inherently generate a key system contradiction that was resolved to bring about this innovation according to Paradigm #1.

With the key system contradiction formed from analysis of the initial and improved states, identification of transformation models that gave way to the innovation can be identified according to paradigm #2. These steps can be repeated for the duration of the technical innovation process until the artifact has reached its present dominant design state resulting in the full picture of the technical evolution according to Paradigm #3.

With the technical evolution established for each subsystem, the transformation models that delivered the innovation can be extracted as a whole. These transformation models will then be charted and graphed to provide a frequency of use for each subsystem and as a whole. The frequency of transformation models realized will fundamentally confirm key transformation model principles that are responsible for innovation in each subsystem and can potentially be applied to resolve future innovation dilemmas in these subsystems. The flow chart of the methodology for Analysis I can be seen in figure 3-1 below.

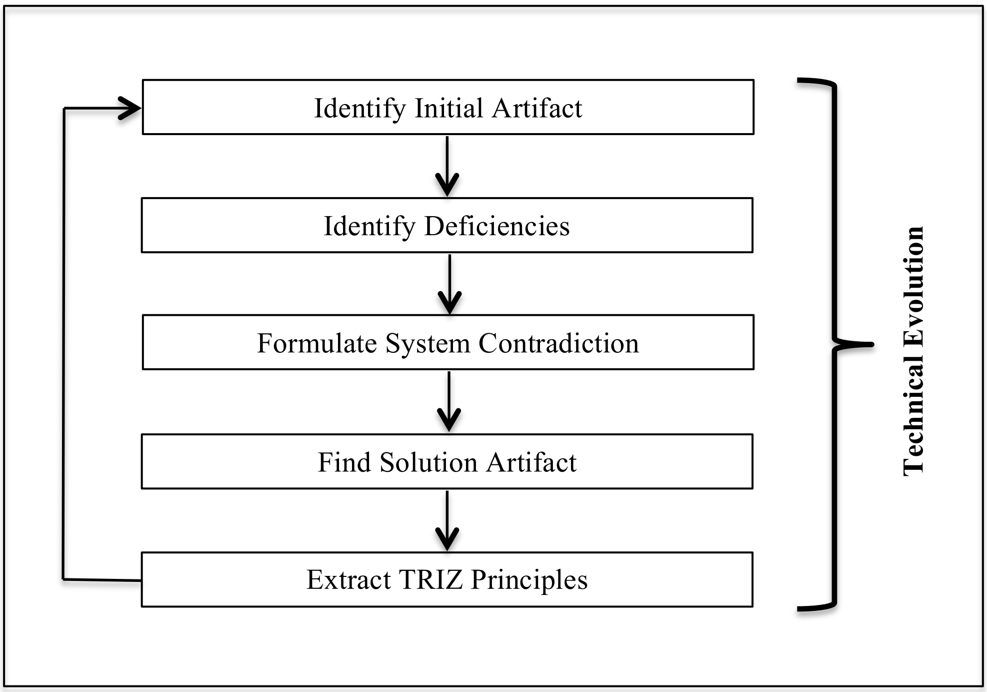


Figure 3-1: Analysis I Methodology

3.6. Methodology Analysis II (Technical Forecasting)

Once the dominant design state has been reached for each subsystem, the forecasting of future technological trends and advancements can be made according to paradigm #4. Technological forecasting of the lawnmower case study will be performed through application of the TRIZ Contradiction Matrix - one of the many key tools of ARIZ.

For each subsystem of the lawnmower, a key system contradiction will be proposed that describes a feature that needs improvement and a feature that is getting worse or we wish to preserve. This system contradiction should be designed with a key solution in mind to emulate the features that are holding back fundamental innovative progress. This is necessary, as the system contradiction must be stated in a way that identifies with the 39 Engineering Parameters. Once the system contradiction is stated in terms of the Engineering Parameters the application of the TRIZ Contradiction Matrix can be applied. The Contradiction Matrix takes the two conflicting parameters and recommends suitable transformation models to resolve the contradiction. The result is a practicable technological forecast of the direction the subsystem will evolve in with respect to the given solutions. These solutions should be analyzed from various perspectives to determine feasibility. This can be seen in the flow chart of the full methodology in figure 3-2 below.

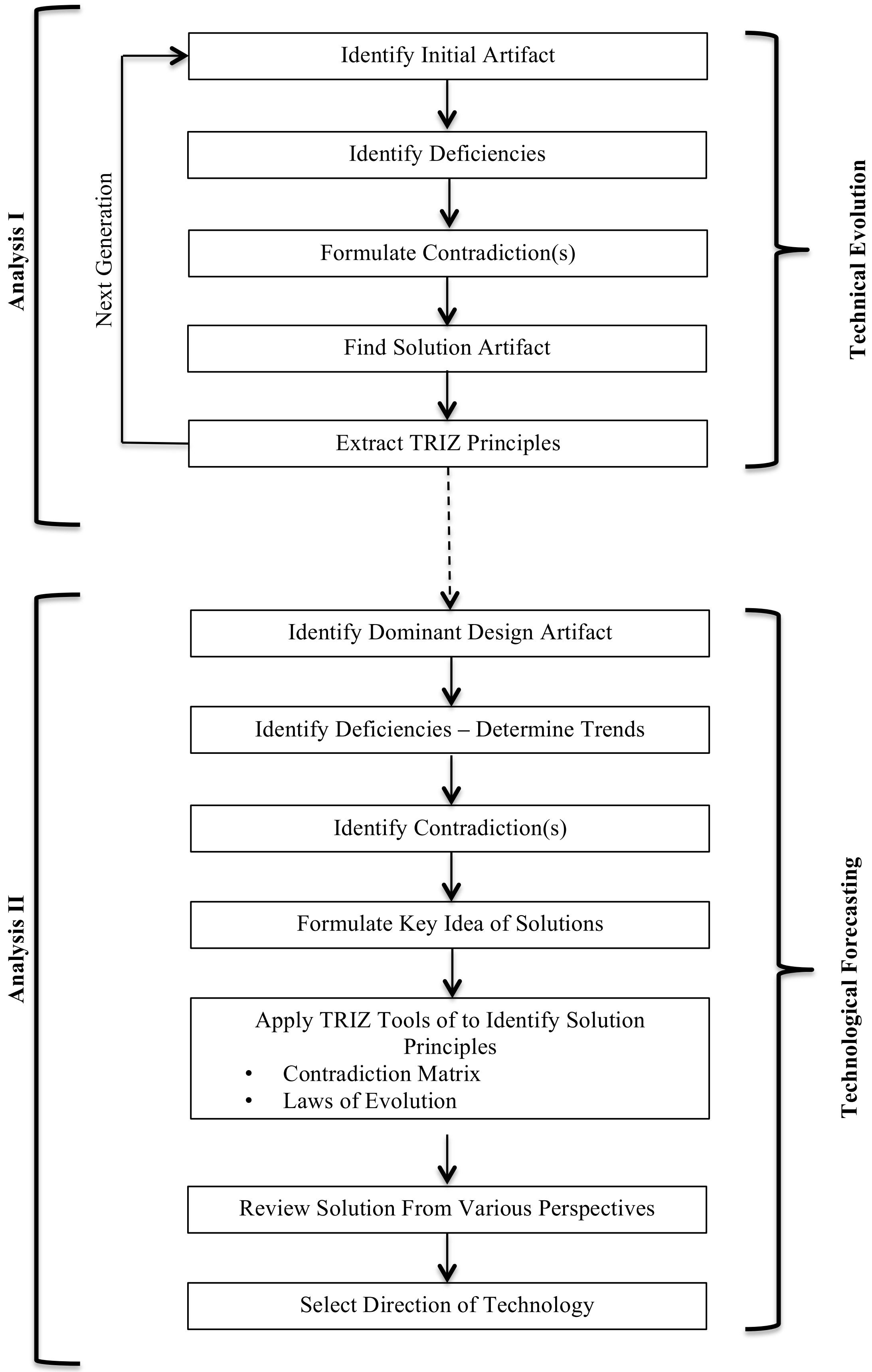


Figure 3-2: Outline of full methodology

Chapter 4 – Analysis I (Technical Evolution)

4.1. General Concept

This chapter contains the TRIZ technical evolution analysis of the push lawnmower case study, from its initial invention to its present day dominant designs. The technological evolution analysis first starts with the invention of the lawnmower in 1830 by Edwin Budding. The first lawnmower was very rudimentary in design and consisted of a large drum with a cutting rotor mounted in the front. Energy to turn the rotor was transmitted via gear-set at a ratio of 16:1. The Edwin Budding mower was made of cast iron and was tremendously heavy to move. A picture of the first mower can be seen in the figure 4-1 below.

Figure: 4-1: The first lawnmower produced in 1830 by Edwin Budding
Source: http://www.digitalstroud.co.uk/images/pages/

Approximately 187 years later, the lawnmower has made vast strides in technical innovation resulting in a dominant design of the rotary mower, which features designs and functions such as the following seen in figure 4-2 below.

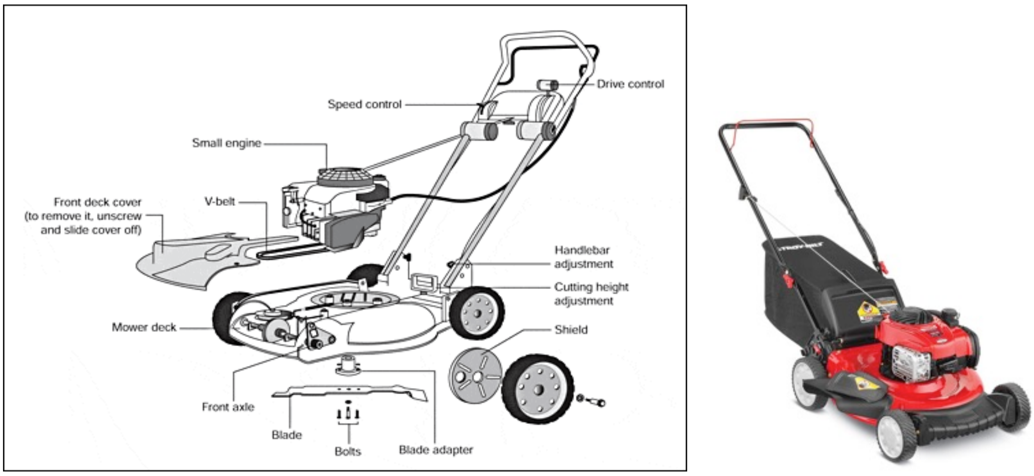


Figure 4-2: Dominant design of rotary lawn mower
Source: http://www.troybilt.com/equipment/troybilt/ &
http://www.top5lawnmowers.com/guideline-for-rotary-lawn-mower-parts/

This chapter aims to extract the technical evolution of the lawnmower according to the methodology stated in Ch. 3 for Analysis I. To best assess technical evolution, the lawnmower is divided into nine subsystems that have universally evolved to form modern day dominant designs and functions. These subsystems and their descriptions can be seen below:

1. ***Mechanics and Mechanical Power (MMP):*** Considers power sources and working components of the lawnmower.
2. ***Cutting Level Control (CLC):*** The ability to adjust the height of the cutting mechanism.
3. ***Transmissions (T):*** Examines the transfer of energy from the power source to the cutting device.
4. ***Cutting Area (CA):*** Examines the effective working area of the lawnmower.
5. ***Discharge and Collection (DC):*** The methods used to expel or dispose of grass clipping, a byproduct of cutting grass.

6. ***Cutting Technology and Blades (CB):*** Examines the different cutting technologies used in lawnmowers.
7. ***Steering and Control (SC):*** Examines wheel placement and overall control of operation.
8. ***Drive-trains (DT):*** Examines the systems that propel a lawnmower.
9. ***Decks (DK):*** Examines the frame and protective covering of the lawnmower.

To best document the technical evolution of each subsystem, a problem code devised of the subsystem prefix and numerical code will be used. The numerical code represents the order of technological evolution with the earliest innovation starting at 01 and incrementally progressing until the dominant designs are reached. The problem code can be seen in the upper left corner of each technical innovation.

The following contains the analysis of the technical evolution of lawnmowers and their extracted transformation models.

4.2. Evolution of Mechanics and Mechanical Power (MMP)

The evolution of technical innovation in mechanics and mechanical power (MMP) takes into account the different cutting methods and power sources that have led to modern day designs in push mowers. The analysis effectively identifies 12 evolutionary innovations that radically changed the lawnmower.

<table>
<tr><td colspan="2">MMP 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1832</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The first reel lawn mower invented by Edwin Buddings was difficult to move due to excessive weight of its construction.

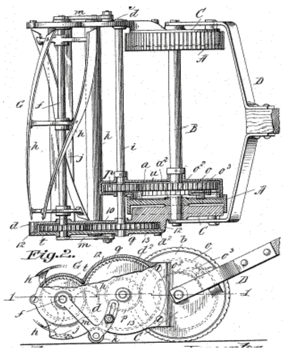
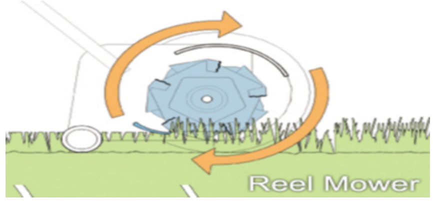
Patent: 3157, 1832</td><td>Machine is made of cast iron, which increases durability and strength.</td><td>Machine is heavy and slow.</td></tr>
<tr><td colspan="2" rowspan="6">
Source: http://www.makingthemodernworld.org.uk/icons_of_ invention/technology/1820-1880/IC.040</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">Edwin Budding made the lawn mower usable by two people – one to push and one to pull.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Do it in reverse
Copying
Mediator</td><td>13
26
24</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1860’s</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Push mowers are hard to move and rotation of cutting drum is difficult due to high friction between moving parts.</td><td>Increase speeds due to higher efficiencies.</td><td>Increase friction in moving parts.</td></tr>
<tr><td colspan="2" rowspan="6">

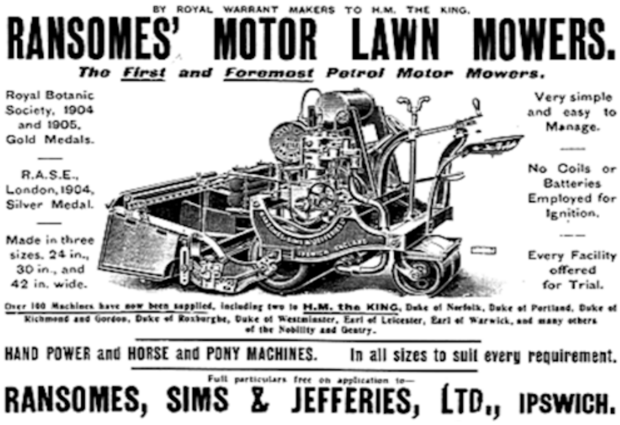
Source: http://www.oldlawnmowerclub.co.uk/forum/history-and-technical/technical/cylinder-bearings</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">Bearings are introduced to axles and cylinder bearings that greatly reduce energy loss to friction.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local Quality
Spheroidality
Mediator</td><td>3
14
24</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1893</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: With larger diameter cutting rollers, it became increasing difficult for the operator to move the mower efficiently.</td><td>Increase efficiency and cutting area.</td><td>The weight of push reel mowers requires much muscle power to move.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

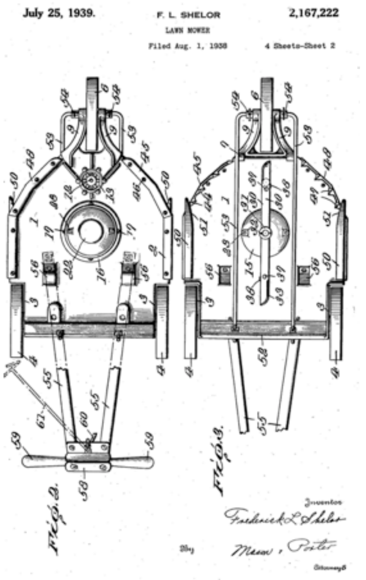
Source:http://www.practicalmachinist.com/vb/antique-machinery-and-history/sumner-steam-engine-152662/index2.html</td></tr>
<tr><td colspan="2">The application of the steam engine to the lawn mower to first performed by James Sumner in Lancaster UK. The application of a steam engine let mower sizes increase in width due to the application of mechanical power.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Replacement of mechanical system
Dynamicity
Continuity of useful action
Mediator</td><td>28
15
20
24</td></tr>
</table>

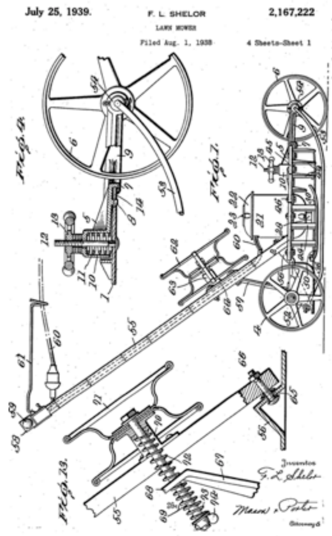
<table>
<tr><td colspan="2">MMP 04</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1899</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: The reel style cutting mowers are cumbersome due to their heavy weight and difficult to control.</td><td>Increase speed, usability, reduce clogging of gears.</td><td>The weight of small push reel mowers requires much muscle power to move.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4"> 


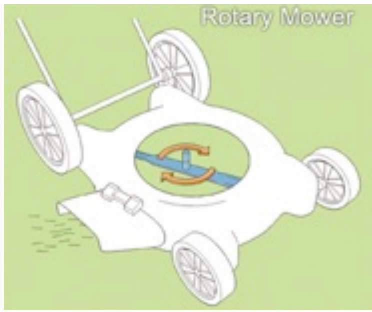
Source: http://blacktimetravel.com/john-burr-invented-the-modern-day-lawn-mower/
http://www.ecomowers.com/Reel_Mowers_versus_Rotary_Mowers_a/150.htm</td></tr>
<tr><td colspan="2">John Burr makes the next largest innovation to the lawnmower by innovating the rotary-blade mower. It reduced the weight tremendously, additionally making it cheap to manufacture. (Bellis, 2017)</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Consolidation
Spheroidality
Dispose</td><td>5
14
27</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 05</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1902</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The steam motor is difficult to use and added much excess weight to the machine. (Kennedy Mike)</td><td>Reduction of weight and introduction of steady power to increase usability.</td><td>Increase of weight and complexity of system.</td></tr>
<tr><td colspan="2" rowspan="5">

Source: http://into--the--abyss.tumblr.com/post/139033376834/scythes-are-for-old-men</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">Ransome's Engineering introduced the first gasoline-powered mower reducing the weight of the steam engine and introducing steady power.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Dispose
Continuity of useful action
Replacement of mechanical system</td><td>27
20
28</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 06</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1939</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Reel mowers are slow and difficult to use. Especially in thick grass where they get bogged down.</td><td>Increase cutting speed and ease of use.</td><td>Difficult to cut thick grass and maneuver.</td></tr>
<tr><td colspan="2" rowspan="12">






Source: US Patent 2167222A (Shelor)
http://www.ecomowers.com/Reel_Mowers_versus_Rotary_ Mowers_a/150.htm</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">In 1939, Frederick Shelor in conjunction with the Richmond Foundry& Mfg. Co. Inc. developed a new style of cutting grass by utilizing a spinning blade. The spinning blade rotates at horizontally at high speeds around a vertical shaft driven by a motor. The blade is made of metal and sharpened at the tips for better cutting. The blade is housed under a metal protective enclosure that is called the deck and which additionally provides the frame for the motor and wheels. The rotary mower is the most common type of mower on the market today.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local Quality</td><td>3</td></tr>
<tr><td>Spheroidality</td><td>14</td></tr>
<tr><td>Transition into a new dimension</td><td>17</td></tr>
<tr><td>Continuity of useful action</td><td>20</td></tr>
<tr><td>Rushing through</td><td>21</td></tr>
<tr><td>Dispose</td><td>27</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 07</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1953</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Traditional gasoline engines are bulky and excessively heavy due to materials (typically a cast iron) they were made from.</td><td>Engine is light which increases efficiency.</td><td>Engine is excessively heavy.</td></tr>
<tr><td colspan="2" rowspan="5">

Source: http://www.vintageadbrowser.com/industry-ads-1950s/14</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">In 1953, Briggs and Stratton produced the first lightweight aluminum engine, designed for the lawn & garden industry. This drastically reduced the weight of the engine and improved ease of use of rotary lawn mower. Result of this made lawnmowers useable by typical households.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Composite Materials</td><td>40</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 08</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1964</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The linear design of travel makes turning difficult in standard mowers.</td><td>Improvement in handeling.</td><td>The standard mower can only travel in linear directions. Turning is difficult.</td></tr>
<tr><td colspan="2" rowspan="5">
Source: http://www.flymo.com</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The hover lawnmower was invented by Karl Dahlman. It was based on the principle of a hovercraft and had no wheels, relying on the cushion of air created by the spinning blade. This made it capable of traveling in any direction.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local Quality
Extraction
Universality
Equipotentiality
Continuity of useful action</td><td>3
2
6
12
20</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 09</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Gas engines are bulky, heavy and hard to operate. Reduction of weight is necessary while increasing power.</td><td>Efficient power usage and decreased weight.</td><td>Weight and complexity complicate use of gas engine.</td></tr>
<tr><td colspan="2" rowspan="5">
Source: http://earthwisetools.com/collection/electric-mowers/</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">It wasn’t until the later parts of the 19th century that electric lawn mowers became feasible. This was mainly due to technological improvements over the decades, which made electric motors smaller, cords safer and more durable, and electronics overall smaller and more user friendly. The electric mower can start and stop on command from the user increasing efficiency.

*Note: Gas mowers maintain popularity over electric mowers for several reasons: (1) The cord keeps a limited working range and (2) gas engines provide more power allowing them to cut thicker grass easier.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Feedback
Replacement of Mechanical System
Continuity of useful action</td><td>23
28

20</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 10</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Early 20th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Early gas motors are inefficient all around and require maintenance. Inefficiencies include over heating of block leading to thermal expansion and breakdowns, high emissions, high vibrations and excessive burn rates. Often they are difficult to start and require multiple priming periods.</td><td>Efficient, light weight, clean.</td><td>Inefficient gas motors.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: http://www.husqvarna.com/us/products/lawn-mowers/</td></tr>
<tr><td colspan="2">Modern small gas engines have been well refined over the ages. They are now lightweight, clean and more powerful than before. Modern small gas engines are designed to be low maintenance, fuel-efficient and provide ample power with low vibration and lower fuel burn. Most modern small gas engines are designed in a modular fashion making them easy to manufacture and easy to fix. Many include modern electronics, which provide feedback to the motor and user as well as quick starts.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Feedback
Composite materials</td><td>1
23
40</td></tr>
</table>

<table>
<tr><td colspan="2">MMP 11</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 2012</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The electric lawnmower needs to be connected to a power source at all times to operate, thus having a limited working range.</td><td>Unlimited working distance from power source and increase safety.</td><td>Limited working distance of electric mower due to cord.</td></tr>
<tr><td colspan="2" rowspan="6">
Source: http://www.blackanddecker.com/products/lawn-and-garden/lawn/lawn-mowers</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The invention of the battery-powered lawnmower was made. This lawnmower uses a strong battery to power an electric motor which spins the rotary blade. The battery is modular in design and can be switched out with another when power is depleted.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Extraction
Nesting
Continuity of useful action
Feedback</td><td>1
2
7
20

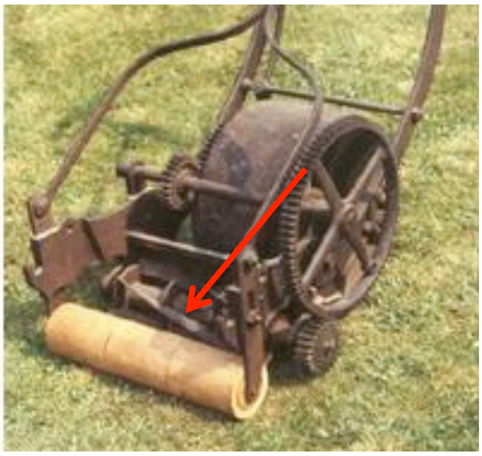
23</td></tr>
</table>

<table>
<tr><td>MMP 12</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td>Date: Early 20th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td rowspan="2">Problem: Traditional lawn mowers require human interaction to control and operate.</td><td>Autonomous control.</td><td>Need human control.</td></tr>
<tr><td colspan="2" rowspan="5">
Source: http://www.husqvarna.com/us/products/robotic-lawn-mowers/</td></tr>
<tr><td>Solution</td></tr>
<tr><td>Robotic mowers are fully autonomous and need no supervision to mow a yard. They can operate on a schedule and have built in sensors and software that allows them to navigate yards with obstacles. These robotic mowers are self-charging and will automatically return to its power base when power is low. This autonomous mower demonstrates Law 6, Law of technical system evolution – the removal of human control to autonomous control and Law 1, Ideality.</td></tr>
<tr><td>TRIZ Transformation Model No.</td></tr>
<tr><td><table><tr><td>Local quality
Consolidation
Prior counteraction
Dynamicity
Feedback
Self service
Composite materials</td><td>3
5
9
15
23
25

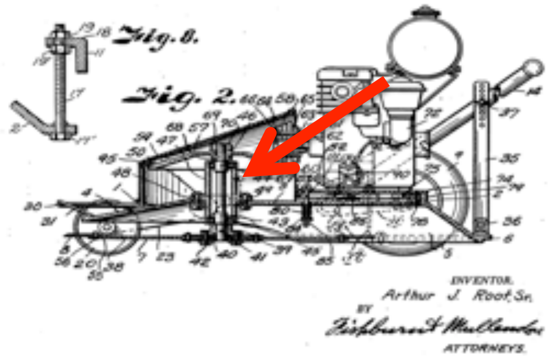
40</td></tr></table></td></tr>
</table>

4.3. Evolution of Cutting Level Control (CLC)

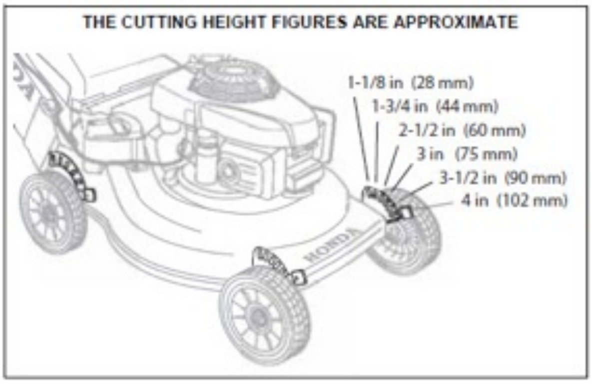
The evolution of cutting level control (CLC) evaluates the technical innovations that have led to modern systems that control the cutting height of grass on modern mowers. Five key innovations were identified in the technical evolution of this sub-system in mowers.

CLC 01		Standard Contradiction	
Date: 1832		*Positive Factor*	*Negative Factor*
Problem: Edwin Budding's reel lawnmower is very primitive and only cut grass at one height.		Increase usability by adding feature to control cutting height.	Ridged connection of elements does not allow for height adjustments.
Solution		 Source: https://alchetron.com/Edwin-Beard-Budding-1119814-W	
Edwin Budding created an adjustable front roller that would allow the height of the cutting drum to be adjustable.			
TRIZ Transformation Model No.			
Counterweight	8		
Copying	26		
Mediator	24		
Dynamicity	15		

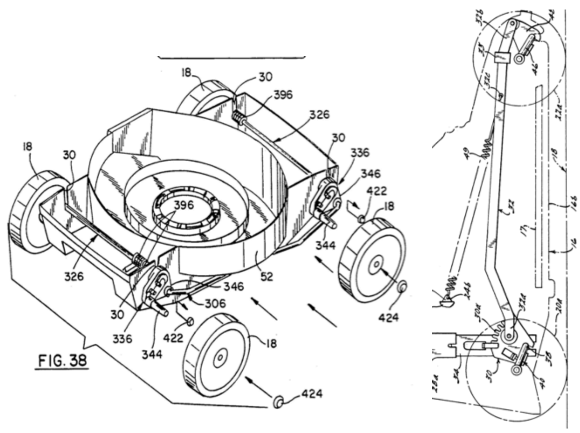
CLC 02		Standard Contradiction	
Date: 1886		*Positive Factor*	*Negative Factor*
Problem: The roller invented by Budding to adjust the height of the cut flattens grass before reaching the cutting reel and is overweight.		Increase usability and reduction of weight.	The roller flattens tall grass making it difficult to cut.
Solution		 Source: https://connecticuthistory.org/reel-lawn-mower-patent-today-in-history/	
Amariah Hills invented small skids that that were adjustable by a screw and could go over bumps due to their round design.			
TRIZ Transformation Model No.			
Extraction	2		
Local quality	3		
Spheroidality	14		
Dynamicity	15		

<table>
<tr><td>CLC 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td>Date: 1946</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td>The cutting height of the rotary mower is non-adjustable.</td><td>Increase usability and control.</td><td>Cutting level of rotary blade mower is fixed.</td></tr>
<tr><td>Solution</td><td colspan="2" rowspan="4">

Source: (Root, 1946)</td></tr>
<tr><td>A play on Amariah Hills' invention is added to the rotary mower. The front wheels are individually adjustable by a screw mechanism.</td></tr>
<tr><td>TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality 3
Spheroidality 14
Dynamicity 15</td></tr>
</table>

<table>
<tr><td>CLC 04</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td>Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td>Problem: Screw mechanism for adjusting height is not east to use and can put mower on an angle if not properly measured on both sides.</td><td>All wheels are equally and similarly adjustable.</td><td>Difficult to adjust separate wheels equally.</td></tr>
<tr><td>Solution</td><td colspan="2" rowspan="4">

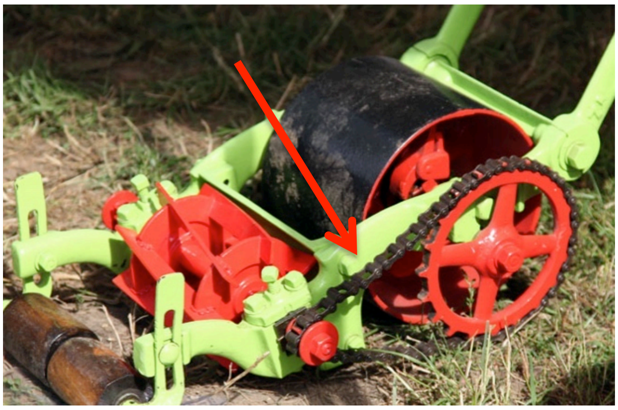
Source: https://powerequipment.honda.com/lawn-mowers</td></tr>
<tr><td>All wheels are individually adjustable with pre-set height settings. The mechanism uses a pre-cut index plate with a locking mechanism on the top end and wheel on other end.</td></tr>
<tr><td>TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality 3
Cushion in advance 11
Spheroidality 14
Dynamicity 15</td></tr>
</table>

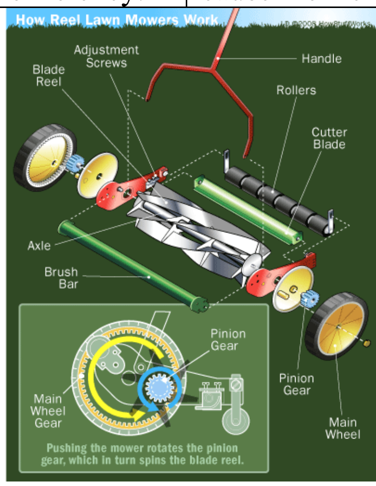
<table>
<tr><td colspan="2">CLC 05</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1993</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Each wheel must be individually adjusted to the proper height.</td><td>Ease of use, efficiency</td><td>Each individual wheel must be individually adjusted with the index plate.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: (Hess, Hare, Jackson, & Bond, 1992)</td></tr>
<tr><td colspan="2">All wheels are adjusted at the same time through a lifting mechanism that uses two tie-bars and a connecting rod to adjust all four wheels at the same time. It uses a pre-cut index plate with pre-defined heights and is executed through a lever by the user.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality
Consolidation
Cushion in advance
Spheroidality
Dynamicity</td><td>3
5
11
14
15</td></tr>
</table>

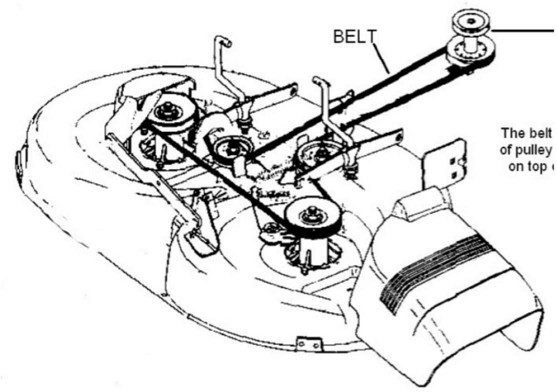
4.4. Evolution of Transmissions (T)

The evolution of transmission in mowers affects the way power is communicated from the source (motor) to the blades. Five key innovations, which evolved this sub-system, were identified.

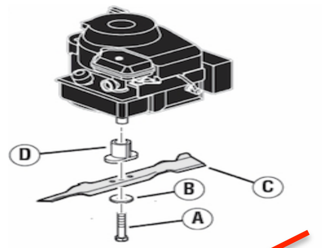
<table>
<tr><td colspan="2">T 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1859</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Edwin Budding’s reel lawnmower is still difficult to move due to excessive weight of its construction and requires two people to use – one to push and one to pull.</td><td>Decrease weight.</td><td>Machine is excessively heavy.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: http://www.gracesguide.co.uk/File:Im20110805PK-Green2.jpg</td></tr>
<tr><td colspan="2">Thomas Green invents the chain drive for the lawnmower in 1852, which slightly reduced the weight of the machine making it easier to push.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Extraction
Asymmetry
Dynamicity
Mediator</td><td>2
4
15
24</td></tr>
</table>

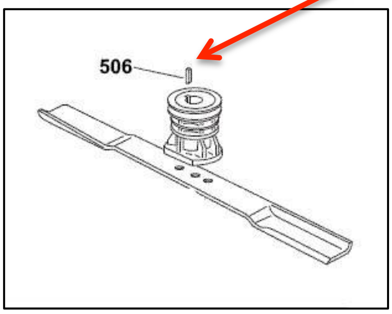
<table>
<tr><td colspan="2">T 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Early 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: External gear sets of reel mowers add weight and decreased durability and efficiency as clippings and other debris got caught between the gears.</td><td>Decrease in weight and increase in efficiency.</td><td>The gears are heavy and cause inefficiencies.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: http://home.howstuffworks.com/reel-mower2.htm</td></tr>
<tr><td colspan="2">The planetary gear set is used internally in the wheel, decreasing weight and eliminating</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Local Quality
Consolidation
Nesting</td><td>1
3
5
7</td></tr>
</table>

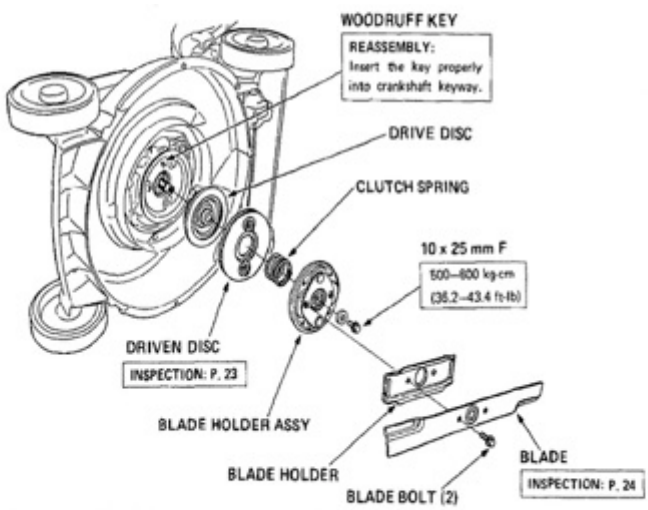
<table>
<tr><td colspan="2">T 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Chains were initially used to drive rotary mowers. They were expensive, heavy and needed precise gearing causing vibrations.</td><td>Increase efficiency and usability.</td><td>Chain drives are heave and expensive to produce.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: http://decks.p293.info/craftsman-mower-deck-wheels/</td></tr>
<tr><td colspan="2">The application of belt driven rotary mowers greatly transformed the modern lawnmower. Everything from transmissions to the running of multiple blades is now performed with belts. Belts are flexible, cheap and easily replaceable. Belts also dampen vibrations previously caused by the rigidities of chains in addition to allowing slip, which prevents the failure in ridged parts.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Extraction
Spheroidality
Dynamicity
Mediator</td><td>2
14
15
24</td></tr>
</table>

<table>
<tr><td colspan="2">T 04</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Mid Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: In modern rotary mowers, the blade is directly attached to the crankshaft of the motor for simplicity and efficiency. In the event that the blade suddenly hits a solid object and stops, the motor will suffer catastrophic damage due to its ridged linkage.</td><td>The shaft must turn if the blade doesn't stop.</td><td>The shaft must turn if the blade stops.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="5">



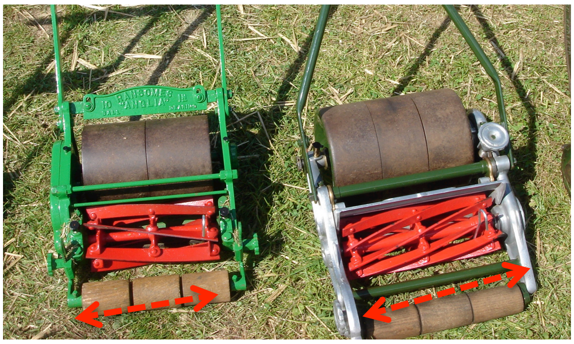
Source: https://www.jungle-busters.co.uk/Mountfield-SP465-SP465R-Woodruff-Key
https://www.snapper.com/na/en_us/support/faqs/browse/how-do-i-remove-blades-from-my-snapper.html</td></tr>
<tr><td colspan="2">The application of a small malleable metal key (Woodruff key) is inserted into the slot of the crankshaft and transfers power from the shaft to the blade. If the mower blade suddenly stops, the metal key is sheared due to its malleability leaving the motor shaft intact.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Nesting
Prior counteraction
Cushion in advance
Dynamicity
Mediator</td><td>7
9
11
15
24</td></tr>
</table>

<table>
<tr><td colspan="2">T 05</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The rotary mower's blade was attached directly to the engine crankshaft. When the motor turned, so did the blade. There was no way to stop the blade unless the motor was turned off.</td><td>The blade must not be connected to the motor.</td><td>The blade must be connected to the motor.</td></tr>
<tr><td colspan="2" rowspan="6">

Source: https://powerequipment.honda.com/lawn-mowers</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The use of a simple clutch separated the two properties. The clutch is manually engaged by the user via cable that engages or disengages a drive and driven disk with a spring. When the spring is released, the disks separate allowing the motor to have continuous operation while the blade stops. When a lever is pressed, it compresses the spring forcing the disks together linking the engine and blade. This feature additionally increases safety, as the blade is not spinning when the operator is not present.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Consolidation
Mediator</td><td>1
5
24</td></tr>
</table>

4.5. Evolution of Cutting Area (CA)

The technical evolution of cutting area (CA) identifies the innovative steps lawnmowers have taken to increase cutting area since its inception. Three key innovations were identified in this sub-system.

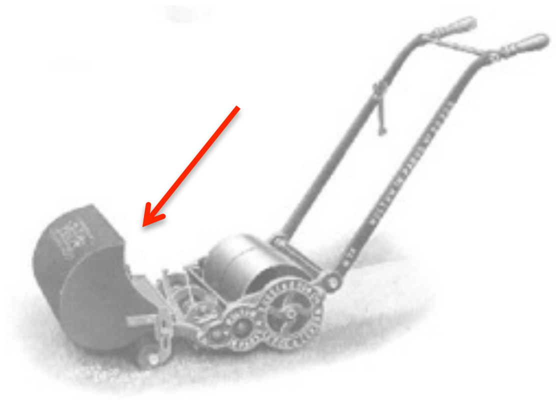
<table>
<tr><td colspan="2">CA 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1862’s</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: The original reel cutter by Budding has a narrow cutting width making the mower inefficient.</td><td>Increase efficiency and convenience of use.</td><td>The mower has an inefficient working area.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: http://tractors.wikia.com/wiki/Lawn_mowers</td></tr>
<tr><td colspan="2">Farrabee’s Company made push mowers with various roller and cutting reel sizes to improve efficiency of cutting area.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality
Partial or Excessive Action</td><td>3
16</td></tr>
</table>

<table>
<tr><td colspan="2">CA 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid to late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Rotary mowers were initially small and had a single blade that cut a narrow width.</td><td>Increase in cutting area</td><td>Small cutting area</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: http://www.homedepot.com/p/Lawn-Boy-21-in-High-Wheel-Gas-Push-Mower-with-Kohler-Engine-17730/204635383</td></tr>
<tr><td colspan="2">Increase blade and deck size to maximize cutting area. The blade is still connected directly to the engine shaft. Modern decks are typically within the range of 14 to 21 inches, which is the maximum approx. width a small gas motor can handle efficiently. Typically a 21-inch mower is running at maximum cutting efficiency of its designed system.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality
Partial or excessive action</td><td>3
16</td></tr>
</table>

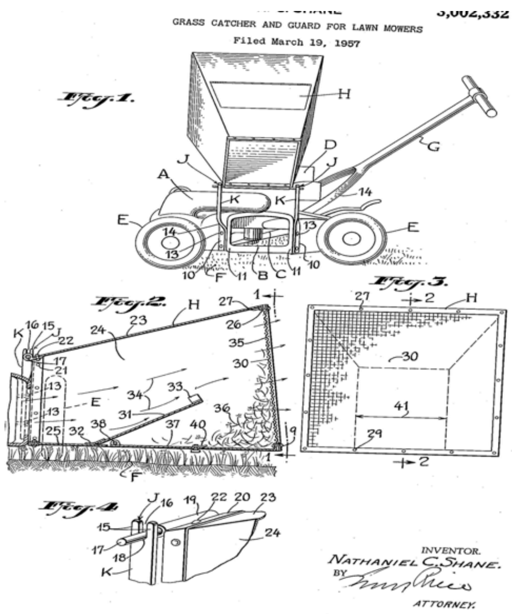
<table>
<tr><td colspan="2">CA 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late Mid 19th Century to Present</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Modern metal rotary blades can only be made so big before they become a hazard to the system and user. The larger the blade becomes the more energy it requires to turn the blade as well as a decrease in cutting efficiency as the blade must make a larger cutting circumference.</td><td>Increase in cutting area and efficiency.</td><td>Inefficient cutting area.</td></tr>
<tr><td colspan="2" rowspan="6">
Source: https://www.deere.com</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The use of multiple short metal blades produce the needed properties to cut grass efficiently and safely. The smaller the blades provide higher cutting efficiency as well as higher control and use less power.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Local quality
Consolidation</td><td>1
3
5</td></tr>
</table>

4.6. Evolution of Discharge and Collection (DC)

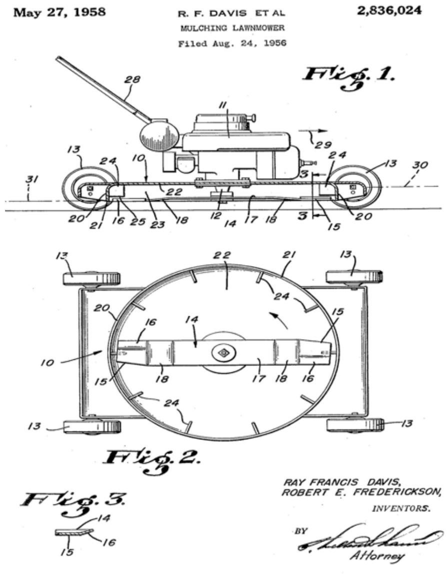
Discharge and collection (DC) takes into account how lawnmowers expel or discharge grass clippings – the byproduct of cutting grass. Seven key innovations were identified that shaped the discharge and collection capabilities of modern lawnmowers.

DC 01		Standard Contradiction	
Date: 1860's		*Positive Factor*	*Negative Factor*
Problem: The cutting reels spewed the grass clipping out the front after cutting. The clippings are a byproduct but needed to be eliminated from the freshly cut lawn.		The clippings are collected naturally.	The clippings are discarded randomly out the front.
Solution		 Source: http://into--the--abyss.tumblr.com/post/139033376834/scythes-are-for-old-men	
The grass collection box attached to the front of the mower was devised, as it would naturally catch the clippings being thrown up after cutting.			
TRIZ Transformation Model No.			
Convert harm into benefit	22		
Transition into another dimension	17		
Mediator	24		
Self-Service	25		

DC 02		Standard Contradiction	
Date: Mid 19th century		*Positive Factor*	*Negative Factor*
Problem: Grass clippings must be expelled from under the deck in a conventional rotary mower to prevent clogging.		Grass clippings are efficiently expelled.	Grass clippings clog the deck.
Solution		 Source: http://forums2.gardenweb.com/discussions/1512697/old-lawn-boy-lawn-mower	
The side discharge was created. It is the simplest and most effective design for expelling grass clippings. The clippings are either expelled through a side or rear opening in the deck.			
TRIZ Transformation Model No.			
Extraction	2		
Local quality	3		
Universality	6		

<table>
<tr><td colspan="2">DC 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 1950’s</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Deflection of grass clippings creates a mess and a hazard as they are flung out the side discharge at high speeds.</td><td>The grass clippings are collected and safety is improved.</td><td>Grass clippings are discarded at high speeds.</td></tr>
<tr><td colspan="2" rowspan="9">

Source: (Shane, 1957)</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">Nathaniel C. Shane invented the grass catcher and guard for lawnmowers. This mesh box effective uses the force that the blade creates to expel clippings into a mesh bin. The mesh bin allows excess air to escape while trapping clippings and other harmful particles that would otherwise pose a danger when traveling at high speeds.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Transition into new dimension</td><td>17</td></tr>
<tr><td>Convert harm into benefit</td><td>22</td></tr>
<tr><td>Mediator</td><td>24</td></tr>
<tr><td>Self-service</td><td>25</td></tr>
<tr><td>Use of porous materials</td><td>31</td></tr>
</table>

<table>
<tr><td colspan="2">DC 04</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: 1950’s</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Grass clippings are a natural by product from mowing. The clippings must be picked up or gathered from the freshly cut lawn.</td><td>Clippings must not be present.</td><td>Clippings must be present.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: (Frederickson & Francis, 1956)</td></tr>
<tr><td colspan="2">The invention of the mulching lawnmower operates by shredding the clippings into fine particles under the deck of the mower utilizing a special spinning blade as a means to recirculate particles until finely chopped. With this type of mower, there is no discharge chute from the deck. The deck is designed to work optimally with the blade.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Universality
Excessive action
Convert harm into benefit</td><td>6
16

22</td></tr>
</table>

<table>
<tr><td colspan="2">DC 05</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Side discharge chute is made of ridged plastic, which may damage objects or mower if unintentionally hit.</td><td>Discharge chute must not be ridged.</td><td>Discharge chute must be ridged.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: https://www.toro.com/en/</td></tr>
<tr><td colspan="2">The application of advanced rubbers that hold a ridged shape but bend willingly when hit.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Composite materials</td><td>40</td></tr>
</table>

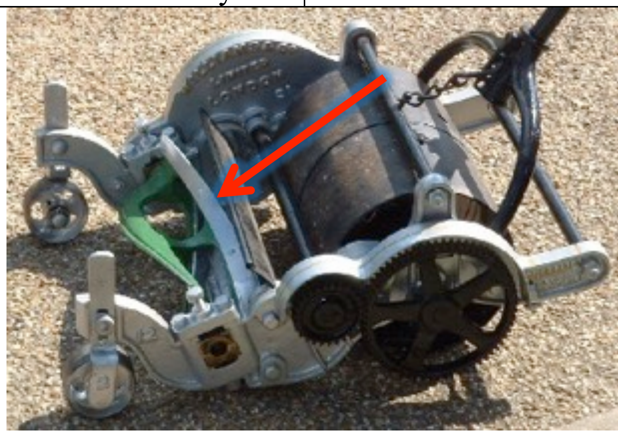
<table>
<tr><td colspan="2">DC 06</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The traditional rotary mower is only capable of performing only one type of discharge or cutting. As result, a consumer would have to buy two mowers to do two types of cutting.</td><td>The mower must be able to mulch clippings.</td><td>The mower must not be able to mulch clippings.</td></tr>
<tr><td colspan="2" rowspan="5">
Source: https://www.lowes.com/pd/Bolens-140cc-21-in-Gas-Push-Lawn-Mower-with-Mulching-Capability</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The application of a closeable door on the side of a rotary mower allows the mower to attain two functions – side discharge when the door is open and mulching capability when the door is closed. This is called a 2 in 1 mower.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation
Local quality
Consolidation
Dynamicity
Mediator</td><td>1
3
5
15
24</td></tr>
</table>

<table>
<tr><td colspan="2">DC 07</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: The 2 in 1 mower lacks the ability to collect clippings.</td><td>2in1 mower must collect clippings at given times.</td><td>The 2in1 mower must not collect clippings at given times.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="9">
Source: http://www.cubcadet.com/equipment/cubcadet/sc-100-hw-sc100hw</td></tr>
<tr><td colspan="2">3 in 1 Mulching lawn mower was created using the opening door principle of the 2 in 1 mower by creating a second door in the back. This door allows the attachment of a bagging device to catch the clippings when the side discharge door is shut and eliminates mulching. This allows the user to perform any cutting and discharge.

1.) Door - for side discharge
2.) Bagging - with rear door and bag
3.) Mulching - close all discharge openings</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation</td><td>1</td></tr>
<tr><td>Local quality</td><td>3</td></tr>
<tr><td>Consolidation</td><td>5</td></tr>
<tr><td>Dynamicity</td><td>15</td></tr>
<tr><td>Mediator</td><td>24</td></tr>
<tr><td>Use of porous materials</td><td>31</td></tr>
</table>

4.7. Evolution of Cutting Blades (BL)

The evolution of cutting blades (BL) assesses the different cutting systems that have been invented in the evolution of the lawnmower. Six different iterations were identified.

<table>
<tr><td colspan="2">BL 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1886</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: When pushed, Budding's reel lawnmower was still inefficient at cutting quickly – especially thick grass.</td><td>Increase cutting power of blades, which increases efficiency.</td><td>Cutting is slow.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="5">
Source: https://connecticuthistory.org/reel-lawn-mower-patent-today-in-history/</td></tr>
<tr><td colspan="2">Amariah Hills opened the spiral of the cutting reel to cut grass more efficiently.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Extraction
Local Quality</td><td>2
3</td></tr>
</table>

<table>
<tr><td colspan="2">BL 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Early rotary blades were individually cut and sharpened making them expensive to replace.</td><td>Increase durability and reduction of cost</td><td>Expensive to manufacture</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: https://www.deere.com</td></tr>
<tr><td colspan="2">Straight mower blade is made of high strength steel. The blade is stamped out of a metal roll and tempered to give it strength and flexibility. The edges of the ends of the blades are then sharpened to provide cutting.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Copying
Homogeneity</td><td>1
33</td></tr>
</table>

<table>
<tr><td colspan="2">BL 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: The straight blade cut grass efficiently but has trouble expelling the clippings, clogging the deck when in thick grass.</td><td>Cuts grass and discards clippings efficiently.</td><td>Inefficient discharge of clippings</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: http://www.oregonproducts.com</td></tr>
<tr><td colspan="2">The ends of the straight blade are slightly angled to provide low airflow that effectively dispels the grass clippings from the mower while keeping dirt and debris levels to a minimum. This blade style is called a low-lifting blade.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality
Universality
Transition into new dimension</td><td>3
6
17</td></tr>
</table>

<table>
<tr><td colspan="2">BL 04</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: The low-lift blade does not provide enough airflow to create suction for bagging and collection or high flow discharge.</td><td>Increase discharge speeds</td><td>Low air circulation.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: http://www.oregonproducts.com</td></tr>
<tr><td colspan="2">The high-lift blade is a more aggressive version of the low-lifting blade. It utilizes deep bends on the end of the cutting blade to provide high airflow and suction. This is especially beneficial for forceful discharge used in bagging and high flow discharge applications. A downside to this design is the need for high HP.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality
Universality
Transition into new dimension</td><td>3
6
17</td></tr>
</table>

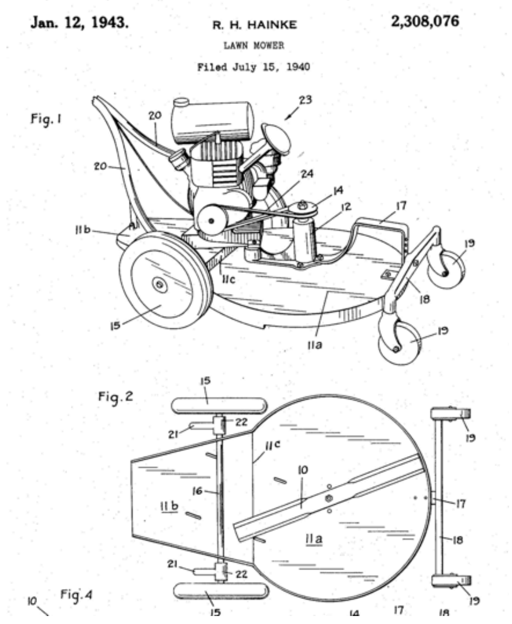
<table>
<tr><td colspan="2">BL 05</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: High-lift blade does not provide re-circulation to finely chop clippings.</td><td>Eliminates need for discharge.</td><td>No recirculation of clippings.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="9">
Source: http://www.oregonproducts.com</td></tr>
<tr><td colspan="2">The mulching blade uses wings and curved baffles at the end of the blade to circulate grass clippings under the cutting deck and back into the cutting blades to create a fine mulch. This design eliminates side discharge and uses the created air circulation lift to recirculate clippings.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local quality</td><td>3</td></tr>
<tr><td>Universality</td><td>6</td></tr>
<tr><td>Spheroidality</td><td>14</td></tr>
<tr><td>Partial or excessive action</td><td>16</td></tr>
<tr><td>Transition into new dimension</td><td>17</td></tr>
</table>

<table>
<tr><td colspan="2">BL 06</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Direct connection of the rotary blade to the engine crankshaft is the cause of catastrophic engine or mower damage when the blade hits a solid object due to its ridged design.</td><td>The blade must not be connected to the motor.</td><td>The blade must be connected to the motor.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="9">
Source: http://www.rover.com.au/Products/Lawn-Mowers</td></tr>
<tr><td colspan="2">A disk mower with attachable blades allows the blades to absorb the shocks of running into solid objects through linked connections that rotate. If damaged, only the small blades need to be replaced which are smaller and cheaper than a full blade.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Segmentation</td><td>1</td></tr>
<tr><td>Local quality</td><td>3</td></tr>
<tr><td>Dynamicity</td><td>15</td></tr>
<tr><td>Mediator</td><td>24</td></tr>
<tr><td>Dispose</td><td>27</td></tr>
</table>

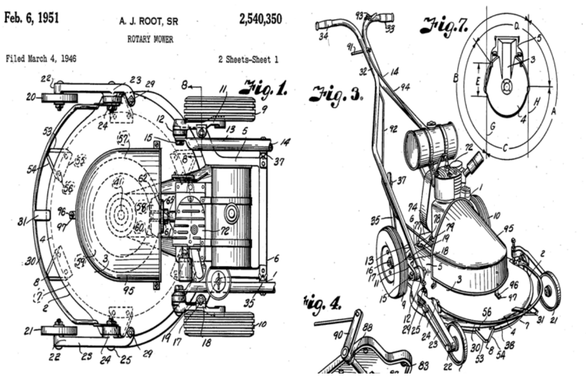
4.8. Evolution of Steering and Control (SC)

The technical evolution of steering and control (SC) of lawnmowers takes into account the different methods that have radically advanced the handling of modern lawnmowers. Four key innovations were identified in this sub-system.

SC 01		Standard Contradiction	
Date: 1940’s		*Positive Factor*	*Negative Factor*
Problem: Turing the lawnmower is difficult as mowers were designed to be linear.		Improve turning and ease of use.	The lawnmower only moves in linear directions.
Solution		 Source: https://1973whsreunion.blogspot.jp/search/label/1939%20 Rotary%20Lawnmower%20Invented%20in%20Warrensburg%20 Leonard%20Goodall	
Remove the rigidities of 4 linear wheels, to two - resulting in a machine truly maneuverable in all directions but lacking ability to maintain cutting height.			
TRIZ Transformation Model No.			
Extraction	2		
Local Quality	3		
Spheroidality	14		
Dispose	27		

<table>
<tr><td colspan="2">SC 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1943</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The lawnmower needs to utilize 3 or 4 wheels to maintain cutting height as well as ease of use as the operator pushes the machine. The ridged connection of the front wheels doesn’t allow the mower to turn.</td><td>Improve steering for safety and usability as well as cutting height.</td><td>Ridged connection of wheels prevent turning.</td></tr>
<tr><td colspan="2" rowspan="5">

Source: (Hainke, 1940)</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The front wheels are mounted on a front bracket with swivels so the mower can turn in any direction as well as maintain cutting height. Additional benefits include safety, as the spinning blade is never exposed during turning maneuvers. An added benefit is the configuration also allows the cutting blade to cut to the edge of the wheelbase with the circular design.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local Quality
Counterweight
Equipotentiality
Spheroidality</td><td>3
8
12
14</td></tr>
</table>

<table>
<tr><td colspan="2">SC 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: 1946</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: The front wheels and skids of lawnmowers crush the tall grass before reaching the cutting rotor, resulting in uncut grass.</td><td>Optimal weight distribution, increase ease of movement.</td><td>Front wheels crush the grass before reaching the blade.</td></tr>
<tr><td colspan="2" rowspan="5">

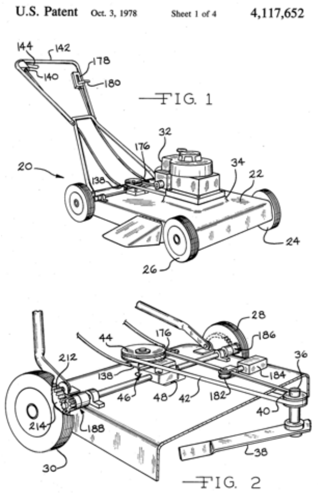
Source: (Root, 1946)</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The rear wheels of the mower are enlarged to carry the weight of the motor while the front wheels are reduced in size and placed to the side of the deck. A belt drives the spinning blade from the motor shaft.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Local Quality
Counterweight
Spheroidality
Convert harm into benefit
Mediator</td><td>3
8
14

22
24</td></tr>
</table>

<table>
<tr><td colspan="2">SC 04</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: Wheels of mowers are made of solid components such as metal and high-density rubbers. This led to great weight of the mower decreasing controllability.</td><td>Reduce weight, Improve controllability</td><td>Heavy weight of solid wheels.</td></tr>
<tr><td colspan="2" rowspan="5"> 
Source: https://powerequipment.honda.com/lawn-mowers</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">Composite wheels made from high-density plastics with a butylene molded outer wheel for grip. The butylene is a rubber like plastic, which also decreases vibration.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Universality
Nesting
Spheroidality
Dispose</td><td>6
7
14
27</td></tr>
</table>

4.9. Evolution of Drive-Trains (DT)

The technical evolution of drivetrains identifies three innovations that have resulted in modern day drivetrain offerings in lawnmowers. Drivetrains are responsible for propelling the lawnmower under its own power.

<table>
<tr><td colspan="2">DT 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2" rowspan="2">Problem: It is difficult to push the lawnmower and the mower wastes extra un-used energy in the driveshaft.</td><td>The lawnmower can propel itself using its own power.</td><td>Muscle power is inefficient to push the lawnmower</td></tr>
<tr><td colspan="2" rowspan="6">

Source: (Cline & Jones, 1976)</td></tr>
<tr><td colspan="2">Solution</td></tr>
<tr><td colspan="2">The creation of a partially self-propelled rear wheel drive (RWD) mower was invented with the addition of a belt driven transmission off the main drive shaft of the mower powering the rear wheels.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Continuity of useful action
Mediator
Self Service</td><td>20

24
25</td></tr>
</table>

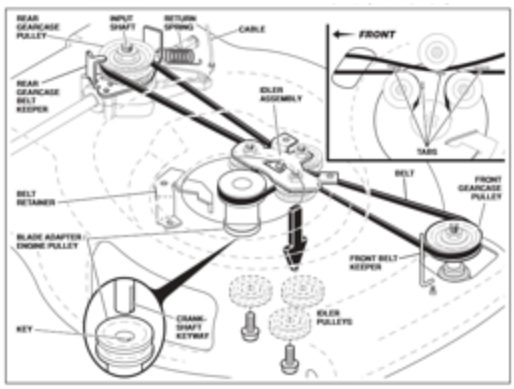
<table>
<tr><td colspan="2">DT 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: RWD mowers have difficulty changing direction.</td><td>Ease of use is increased as well as turning ability.</td><td>Turning is difficult.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">

Source: https://www.craftsman.com/products/craftsman-pro-series-8-5-engine-torque-front-wheel-drive-mower</td></tr>
<tr><td colspan="2">The front wheel drive (FWD) mower is created, propelling the front wheels (as the name suggests) using the same belt driven system as the RWD mower except with an axel in the front.

Note: The FWD mower is inefficient at climbing hill or steep slopes and is made for flat areas.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Continuity of useful action
Mediator</td><td>20

24</td></tr>
</table>

<table>
<tr><td colspan="2">DT 03</td><td colspan="2">Radical Contradiction</td></tr>
<tr><td colspan="2">Date: Early 20th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: FWD is good for flat terrains with few obstacles as FWD pulls the mower. RWD makes it difficult for the user to change direction.</td><td>The mower must not be pulled, but be pushed.</td><td>The mower must be pulled, not pushed.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">



Source: http://www.husqvarna.com/us/products/lawn-mowers/lc221a/961450026/</td></tr>
<tr><td colspan="2">AWD is created to tackle hilly terrain and move the mower in any condition. It combines the principles of FWD and RWD using the same mechanisms as can be seen in the diagram.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Consolidation
Continuity of useful action</td><td>5

20</td></tr>
</table>

4.10. Evolution of Mower Decks (DK)

A lawnmower deck is the metal body and frame that covers the spinning blade on the modern rotary mower and supports the motor. The rotary mower deck has undertaken four innovative steps to result in modern forms.

<table>
<tr><td colspan="2">DK 01</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Mid 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Cast iron decks on early rotary mowers were excessively heavy and difficult to move, often made out of cast iron or steel.</td><td>Decrease in weight and increase in durability.</td><td>Mower deck is heavy making mower difficult to push.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="5">
Source: https://www.lawnboy.com/</td></tr>
<tr><td colspan="2">The mixed alloy cast deck was created, resulting in a lighter deck with ridged properties. Magnesium was an often additive as it was light and strong.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Composite Materials</td><td>40</td></tr>
</table>

<table>
<tr><td colspan="2">DK 02</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Cast mix alloy decks are still relatively heavy and expensive to manufacture.</td><td>Mower deck becomes light, cheap and quick to produce.</td><td>Mixed-alloy casting is time consuming to make and heavy.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="4">
Source: http://www.ssprod.com/deep-drawn-stamping-steel-cutter-housing-lawn-garden.html</td></tr>
<tr><td colspan="2">Stamped steel metal decks are invented. A large press shapes high gauge sheet metal in a deck form, precutting holes in the process. This makes decks cheap, durable, light and easy to manufacture. Strength is maintained in the frame due to its curves instead of sharp bends.
This is still the most common type of mower deck on the market today.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Spheroidality
Homogeneity</td><td>14
33</td></tr>
</table>

<table>
<tr><td colspan="2">DK 03</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Late 19th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Stamped steel decks rust and are still moderately heavy.</td><td>Mower decks become even lighter and more durable.</td><td>Stamped decks rust.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="5">
Source: https://powerequipment.honda.com/lawn-mowers</td></tr>
<tr><td colspan="2">Aluminum decks are lighter and don't rusts.
Note: A downside to aluminum decks is the relatively high cost to manufacture compared to stamped sheet metal decks.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Composite Materials</td><td>40</td></tr>
</table>

<table>
<tr><td colspan="2">DK 04</td><td colspan="2">Standard Contradiction</td></tr>
<tr><td colspan="2">Date: Early 20th Century</td><td>Positive Factor</td><td>Negative Factor</td></tr>
<tr><td colspan="2">Problem: Aluminum decks are expensive to cast and take much time to manufacture, resulting in high prices.</td><td>Decks maintain durability, reduced weight, do not rust and are cheap to manufacture.</td><td>Al decks are expensive.</td></tr>
<tr><td colspan="2">Solution</td><td colspan="2" rowspan="5">
Source: http://www.lawnmowerhut.com/wp-content/uploads/2015/12/petrol-lawnmower-blade-photo.jpg</td></tr>
<tr><td colspan="2">The reinforced plastic deck was invented. Plastic flexes naturally and is corrosion resistant. With modern additives, plastic is stronger than metal in some cases and east to manufacture. This makes it cheap to produce and supports the growing industry of robotic mowers that need unique decks and light weight.</td></tr>
<tr><td colspan="2">TRIZ Transformation Model No.</td></tr>
<tr><td>Composite Materials
Dynamicity
Spheroidality</td><td>40
15
14</td></tr>
</table>

Chapter 5 – Analysis II (Forecasting)

5.1. General Concept

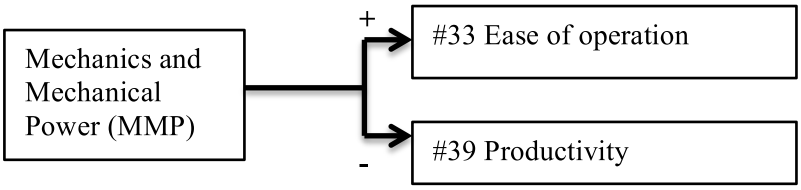
Chapter five is a continuation of chapter four and contains the technological forecasting analysis of push lawnmowers according to the TRIZ method. Previously in chapter 4, the technological evolution of the lawnmower and its key subsystems were analyzed up to present day dominant designs. This chapter addresses each of the nine identified subsystems and creates a forecast of technological development using the TRIZ contradiction matrix. For each subsystem, a primary system contradiction will be proposed. From the identification of this system contradiction, the TRIZ matrix will be used to identify a key parameter that is getting better and worse, which will result in the documentation of evident transformation models that can serve to advance the technology. These identified transformation models will then be applied in theory, to forecast evolution of the system. The following contains the technological forecast of the lawnmower.

5.2. Forecast of Mechanics and Mechanical Power

The mechanics and mechanical power (MMP) of the push mower describe the motor and different cutting methods that have led to present day dominant designs. At present four dominant designs are being produced for the push mower which include:

- Gas powered rotary lawnmower
- Electric rotary lawnmower
- Battery powered lawnmower
- Autonomous lawnmower

The forecast of technological development in this sector needs to encompass shared traits across these designs. In any case the most important aspect is productivity of the system. This is the trait we wish to improve upon and thus designated in the (-) column. The trait we want to preserve is the ease of operation and can be seen denoted in the (+) column. When assessed in the TRIZ contradiction matrix, the following properties are suggested.

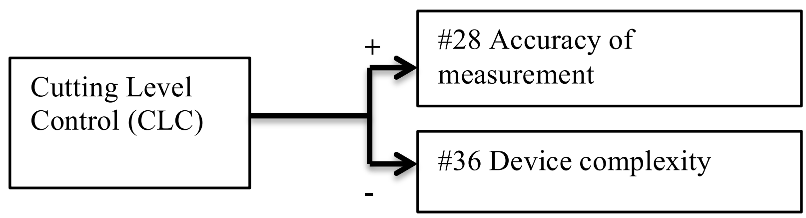


TRIZ Contradiction Matrix Solutions			
#1 Segmentation	#28 Replacement of mechanical systems	#7 Nesting	#10 Prior action
Description			
Segmentation is the division of parts into individual components able to perform functions to a higher degree of performance. It also includes modularization of like components to ease the use of a system. Increasing the degree of segmentation serves to make a system more versatile and less susceptible to outside forces.	The consideration that mechanical systems can be changed in favor of electrical, magnetic, electromagnetic, optical, acoustical, thermal or olfactory equipment that perform functions on a higher level. This is especially critical in autonomous mowers. Varying these fields may additionally produce desired results.	The application of placing one part inside another or fitting one part to another. This can be seen in the battery-powered mowers where the battery fits inside the motor housing snugly and can be changed intermittently.	Prior action is the act of doing something before it is needed. For example, changing the batter of the cordless mower before it needs to be used.

From the contradiction matrix the move toward a more segments and modular design, use of unseen fields of energy and application of nesting are key hints of future trends in this sector. From the start, #28 and #10 can be applied to describe the problem with battery powered and electric mowers – they need a connected supply of power at some time to function. Applying #28 and #10, leads to the application of wireless charging or transfer of electricity. While this is a long way off, it is especially possible to run sensory cables underground that will guide the autonomous mower around obstacles. Considering the other solutions, the future of mowers will incorporate a more modular design to maximize functionality of each parameter, with some functions being incorporated inside another. This will in turn increase productivity.

5.3. Forecast of Cutting Level Control

To forecast the technological evolution of cutting level controls (CLC), the key system contradiction must first be formed. In CLC, the parameter that is always improving is the measurement accuracy. This is done so at the expense of the device complexity. Thus the system contradiction is as follows:

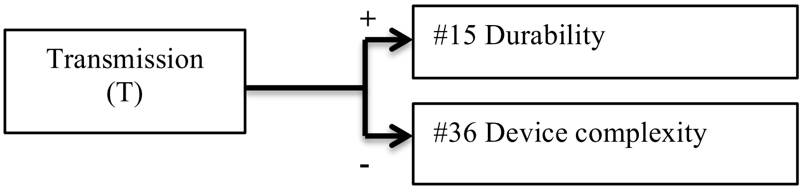


TRIZ Contradiction Matrix Solutions			
#27 Dispose	#35 Transformation properties	#10 Prior action	#34 Rejecting and regenerating parts
Description			
Dispose applies short lived and cheap parts instead of expensive originals. Of the present mower CLC design, what can be eliminated and replaced with a cheap part.	Transformation models refer to the change of the lawnmowers degrees of flexibility to better achieve desired effects.	Prior action takes into account changes that need to take place before they occur as well as designing systems so they can come into action from the most effective place possible.	This solution takes into account applying parts that will eventually be worn away and discarded or the reconstruction of consumable parts.

From the TRIZ contradiction matrix solutions, the application of future innovations in cutting level control should include short-lived and replaceable designs. One effective design is using a plastic half-hemispherical skid under the rotor to balance the front of the mower as well as provide a preset height. This is especially applicable in the autonomous motor and will further reduce weight and design complexity. When the skid is worn down over a long period of time, a new one can easily be replaced, or removed for a different height skid to provide variable cutting levels.

5.4. Forecast of Transmissions

The forecast of transmissions in lawnmowers serves to transfer the energy from the motor to the blade. Future innovations need to maintain simplicity but durability, thus the parameter that needs to be improved is durability of the moving components. The parameter that gets worse with development of durability is the complexity of the device. Thus the contradiction matrix and TRIZ matrix solution can be seen below.

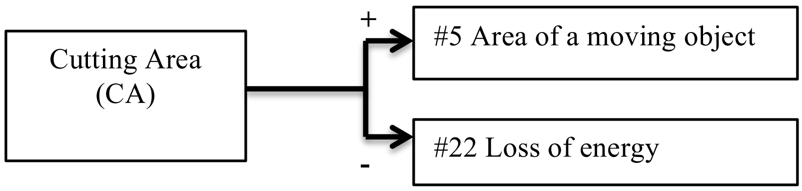


TRIZ Contradiction Matrix Solutions			
#10 Prior action	#4 Asymmetry	#29 Pneumatic or hydraulic construction	#15 Dynamicity
Description			
Anticipation of an action to mitigate the adverse effects of an event. Sensors can alert a system to provide a different action before an adverse effect takes place on the system.	Take advantage of using different dimensions a object can encompass. This includes changing the shape of components from symmetrical to asymmetrical.	Pneumatic or hydraulic components are extremely efficient at transmitting power and should be used to replace bulky mechanical systems that do not provide adequate power.	The creation of systems that is able to handle external changes. This can be accomplished through dividing an object into multiple sections that move relative to each other. It also includes the use of suspension systems that mitigates harmful effects an outside environment would otherwise take on the system.

From the TRIZ solutions, the most viable solution to future innovation in lawnmower transmissions is the use of #29 pneumatic or hydraulic components. Hydraulic components are renown for their transfer force and energy with minimal complexity making them an ideal candidate. Application of a simple but cheap hydrostatic transmission or drive will greatly increase the durability of the device while maintain its simplicity. An example of small hydrostatic drives can recently be found in the hand drill industry. Further application of this technology to the lawnmower industry will provide mowers with greater power transfer potential.

5.5. Forecast of Cutting Area

The forecast of technical innovation in cutting area observes a system conflict that marks the increase of working area as the characteristic to be improved. When working area improves it causes a simultaneous loss rotational energy in the blades, as more energy is needed to turn the larger or multiple blades with the same amount of power. Thus the parameter that is getting worse is the loss of energy in the system. The system conflict diagram and resulting TRIZ solutions for the cutting area can be seen below.



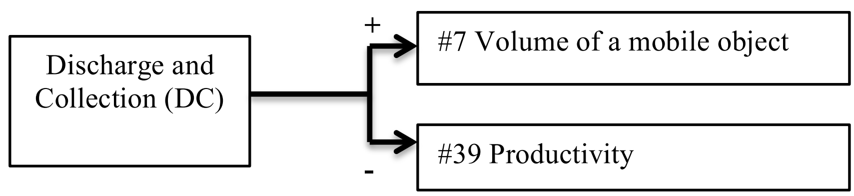
TRIZ Contradiction Matrix Solutions			
#15 Dynamicity	#17 Transition into a new dimension	#30 Flexible films or thin membranes	#26 Copying
Description			
The optimal operation conditions must be met both externally and internally within the system through division of parts capable of movement to expand adaptability of the system.	The application of using a second or third dimension to enhance innovation by potentially using a multi level design or new blade designs, which are bent to reflect or transfer energy more efficiently.	The use of flexible films and membranes provide low cost and great flexibility as well as properties of separation. Application of this could be in washers or press-plates which can help rotational parts move more efficiently, cheaply.	Copying refers to using a cheap or simply copy of the original expensive part.

The solutions of the TRIZ matrix point to four transformation properties that will most likely play a role in future innovations in the advancement of cutting area. These include #15 (Dynamicity), #17 (Transition into a new dimension), #30

(Flexible films or thin membranes) and #26 (Copying). The most immediately applicable principles would be #15 and #30 where a FEA analysis of different designs could be performed to assess maximum efficiency as well #17 in which modern films and membranes could act a lubricating joints, decreasing friction loss in components.

5.6. Forecast of Discharge and Collection

The forecast of technical innovation in discharge and collection observes an already well-developed system. Especially the 3-in-1 mowers that can preform mulching, side discharging and bagging. To further innovate in this area, the postulation that increased cutting efficiencies additionally increases the rates of discharge or volume of discharge is made. When this occurs the productivity of traditional discharge and collection methods decreases leading to the following system contradiction and TRIZ matrix solutions.

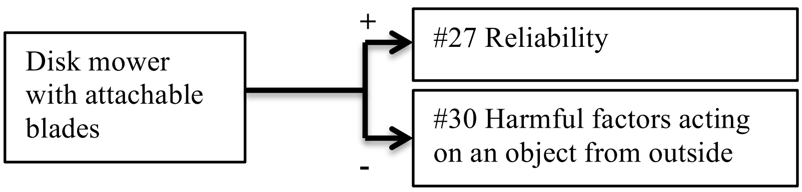


TRIZ Contradiction Matrix Solutions			
#10 Prior Action	#6 Universality	#2 Extraction	#34 Rejecting and regenerating parts
Description			
Prior action indicates addressing a problem before it occurs in such a way that the system can handle the problem when it occurs. This is the knowledge that higher discharge rates will inherently clog small discharge chutes and placement of optimal discharge locations should be sought as well as size.	Universality takes into account that a part can perform multiple functions. If a function can be designated to another part, the original part can then be discarded. This is an example of the mulching feature blade – it can mulch or discharge grass. Research into bagging operations should be considered.	Extraction is the removal of a part that holds back the system or separates it from the other parts that are working efficiently. It also singles out low-value parts for removal and high-value parts for adjustment.	When a part has finished performing its useful function, it should be eliminated or modified to continue efficient performance. On the other hand, parts that are consumed during operation should be naturally regenerated.

From the contradiction matrix solutions, #10 (Prior Action), #6 (Universality), #2 (Rejecting and regeneration parts) should be strongly considered for technical evolution in discharge and collection innovation models. Prior action is accounting for higher discharge rates more efficient mowers will have, as well as anticipating for modular attachments. This can include the introduction of a new part, which may help discharge. In universality, instead of using a front and side door for different functions (bagging and discharge), the mower can be reduced to one door with multiple functions and better placement. Additionally, the bagging device could collapse instead of being removed adding extra parts. In rejecting and regenerating parts, the bagging collection of clippings is of strong interest. Once full, the bag is typically emptied in a trash receptacle for natural waste then re-attached to the mower. Instead, can the trash receptacle be turned to a naturally disposable bag that can attach to the mower in the function of a bag and when full, simply be disposed of?

5.7. Forecast of Blades

To forecast the technological evolution of blades, a key system contradiction must be formed. As discovered from the analysis of technological evolution, cutting blade technology in lawnmowers must be durable, efficient, cheap, provide lift and prevent harm from other components. Using the latest innovation [BL 06] as the most advanced state, a new system contradiction can be formulated which can be seen below as well as the TRIZ matrix solution.

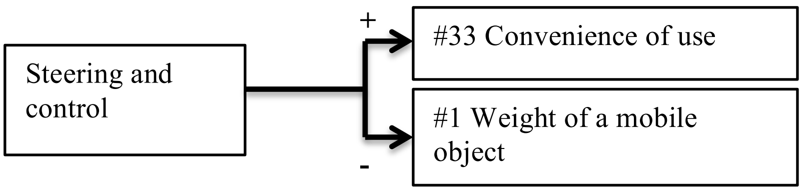


TRIZ Contradiction Matrix Solutions			
#2 Extraction	#27 Dispose	#35 Transformation properties	#40 Composite materials
Description			
Further segment low cost and high cost items, removing low cost ones and relocating high cost ones.	Removal of the metal blade and replacement with an even cheaper short-lived solution.	Physical alteration to the state of the blade to offer greater density or flexibility.	The use of modern composite material to create a new, cheaper stronger material.

The contradiction formed is the age-old contradiction of blades. Reliability increases with new technologies, but the external harmful factors acting on the blade will always wear it away or cause damage to it. From the TRIZ solutions, future blades will be made out of composite materials with greater density to prevent damage, but at the same time be cheap and short lived. Such examples of this could be composite plastic wire that when whipped about, act in the same manner as a blade. Additional solutions could reside in the application of a self sharpening blade or regenerating cutting wire.

5.8. Forecast of Steering and Control

In steering and control, convenience of use is the most essential parameter to control. The easier it is to use, the greater control the user has over the system. This can be seen in the technological evolution of this subsystem above in Ch.4. To formulate the system contradiction, the ease of use is taken as the parameter that is improving while the weight of the steering and control are taken to be increasing thus making the system heavier. This is because an ideal system would eliminate the part according to Law 1 (Ideality) of technological evolution, thus as long as the object is present, its weight an issue.

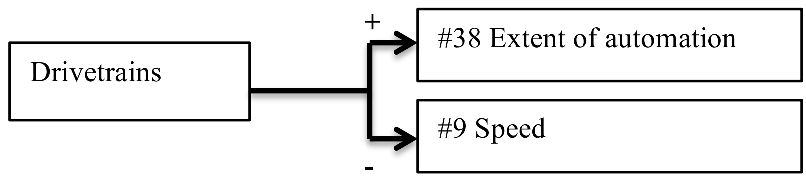


TRIZ Contradiction Matrix Solutions			
#2 Extraction	#13 Do it in reverse	#15 Dynamicity	#25 Self service
Description			
Further segment low cost and high cost items, removing low cost ones and relocating high cost ones. This can also be applied to the position of parts. Relocate poorly positioned parts while keeping optimally placed parts.	Do the opposite or invert parts. Use larger wheels in the rear to enhance control and turning as well as weight distribution.	Continue to alter the system to withstand external changes. Such changes include using suspension, separation of parts, flexible connections and cushions.	The system must be able to care for itself as well as make use of wasted energy. Combination of different functions may achieve this, such as using engine power to generate electricity which run sensors that can help steer or monitor speeds.

From the TRIZ solutions, the forecast of steering and control show that advanced systems must be able to better cope with the external environment and self-service. Such examples of this could be larger diameter wheel sizes in the rear, the addition of a suspension system or better location of wheel placement to counteract weight distribution. In the move to autonomous mowers, the needs for mowers to self-service and steer for themselves is critical. This can be performed with sensors that when optimally placed reduce costs and increase control.

5.9. Forecasting of Drive-trains

The forecast of drivetrains in lawnmowers, takes into account the different methods of propulsion with the pinnacle of innovation being the AWD system found in [DT 03]. While current drive-trains make using the lawnmower easier, it does have its drawbacks as the mower moves at one speed, with jerky starts and stops. The speed can either be too fast or slow for efficient use or comfort. Thus the derived system contradiction with current drive-trains is to improve the extent of automation to better match the speed of the user and cutting condition with respect to the speed the mower can currently produce.

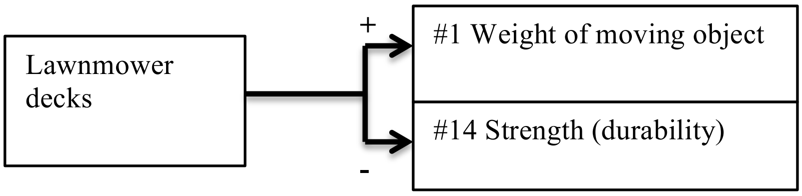


TRIZ Contradiction Matrix Solutions	
#28 Replacement of mechanical system	#10 Prior Action
Description	
Principle #28, replacement of mechanical system recommends the replacement of the current mechanical system with one of a sensory capable means. This includes using electric and magnetic fields.	Prior action indicates addressing a problem before it occurs in such a way that the system can handle the problem when it occurs.

For this system contradiction, the TRIZ contradiction matrix only offers two solutions. The first #28 (Replacement of mechanical systems) recommends that future innovations in drivetrains will utilize more advanced technologies such as electric motors capable of receiving feedback and automatically being able to adjust cruising speeds. Second, principle #10 (Prior action) aims to deliver a device that can react to external changes that call for changes in speed. Innovations such as load sensors attached in the motor which identify when the rotor is being bogged down are needed to slow the mowing speed to maintain efficiency. Additionally innovation in user handling such as prior action to identify user walking speeds is a probable next step of push mowers.

5.10. Forecast of Decks

The technical evolution of lawnmower decks is one of durability and weight reduction as can be seen in Ch. 4. The future of mower decks is understandably one of strength it supports the motor, delivers safety and provides a frame for the wheels and handles to mount to. Thus the system contradiction and TRIZ matrix solutions can be seen below.



TRIZ Contradiction Matrix Solutions			
#1 Segmentation	#8 Counterweight	#15 Dynamicity	#40 Composite materials
Theoretical Solutions			
Segment the deck into independent parts. Make critical parts more durable and vice-a-versa. Moreover, utilize modularity in design.	To compensate for the weight of the deck, use other parts to provide a upward thrust that will offset the weight. A potential solution is to utilize the blade as a fan to provide thrust.	The idea behind this principle is to allow the characteristics of the deck to work at optimal conditions. This could consist of a process change or dividing the deck into parts capable of moving relative to each other.	The use of modern composite material to create a new, cheaper stronger materials that can serve as decks or other features in the deck where durability may not be needed.

The mower deck is a vital component of the lawnmower. As suggested by the TRIZ contradiction matrix, future generation of mower decks will encompass segmentation, especially through material use. This could be accomplished by using a high strength composite material for the rotor housing, while using a more moderate and cheap material for the rest of the frame. Additionally, the lawnmower deck, as we know it today may change to become more dynamic to outside forces. Such suggestions could include a flexible joint that breaks the deck into segments to better tackle rough terrain.

Chapter 6 –Recommendations

6.1. Recommendations from Analysis I (Technological Evolution)

From the full analysis of technical evolution in lawnmowers, the extracted transformation models were obtained for each step of technical innovation of the nine subsystems. These extracted transformation models when observed as whole, fully describe the technical evolution of the lawnmower (as a single primary system) to present day dominant designs. This can be seen in table 6-1 where the nine subsystems are listed on the left column and their respective transformation models that produced technical evolution listed to the right.

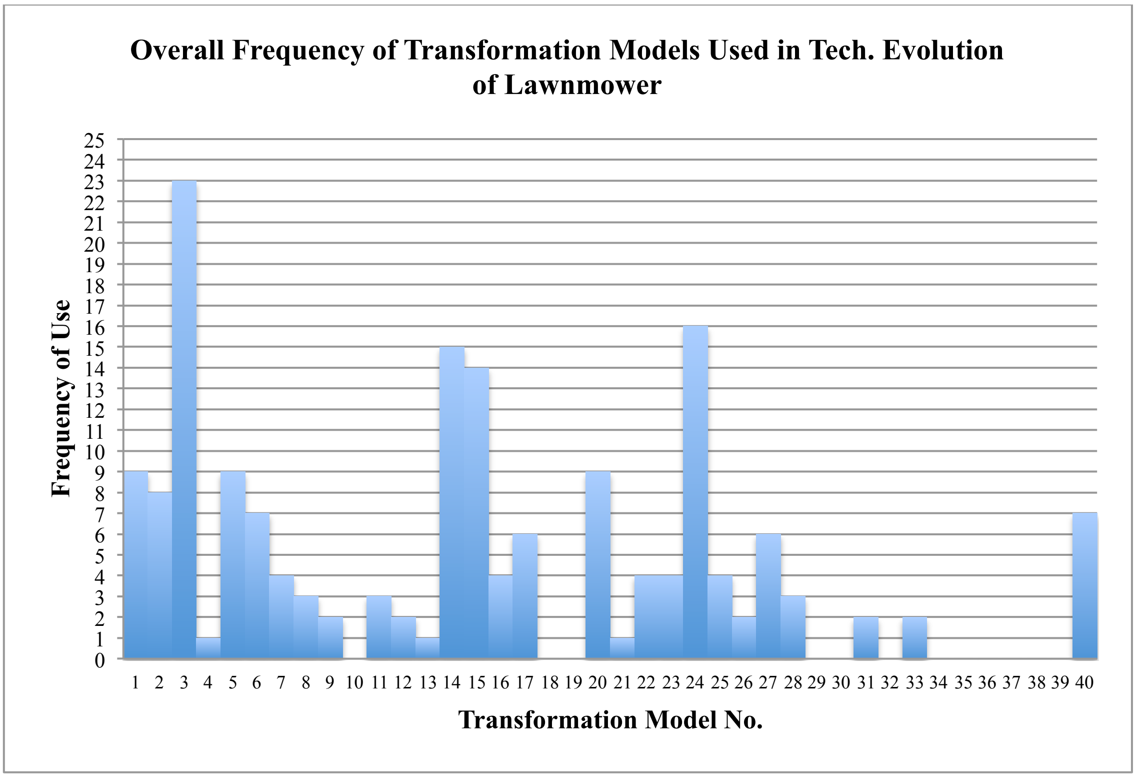
From the table, the overall frequency of transformation models used through the general evolution of the lawnmower is then charted in table 6-2 to determine which transformation models have had the greatest impact in the development of the lawnmower. These frequencies are then plotted in graph 6-1.

Subsystem	*Innovation No.*	TRIZ Transformation Model No.						
Mechanics and Mechanical Power	*MMP 01*	13	24	26				
	MMP 02	3	14	24				
	MMP 03	15	20	24	28			
	MMP 04	5	14	27				
	MMP 05	20	27	28				
	MMP 06	3	14	17	20	21	27	
	MMP 07	40						
	MMP 08	2	3	6	12	20		
	MMP 09	20	23	28				
	MMP 10	1	23	40				
	MMP 11	1	2	7	20	23		
	MMP 12	3	5	9	15	23	25	40
Cutting Level Control	*CLC 01*	8	15	24	26			
	CLC 02	2	3	14	15			
	CLC 03	3	14	15				
	CLC 04	3	11	14	15			
	CLC 05	3	5	11	14	15		
Transmission	*T 01*	2	4	15	24			
	T 02	1	3	5	7			
	T 03	2	14	15	24			
	T 04	7	9	11	15	24		
	T 05	1	5	24				
Cutting Area	*CA 01*	3	16					
	CA 02	3	16					
	CA 03	1	3	5				
Discharge and Collection	*DC 01*	17	22	24	25			
	DC 02	2	3	6				
	DC 03	17	22	24	25	31		
	DC 04	6	16	22				
	DC 05	40						
	DC 06	1	3	5	15	24		
	DC 07	1	3	5	15	24	31	
Cutting Technology and Blades	*BL 01*	2	3					
	BL 02	1	33					
	BL 03	3	6	17				
	BL 04	3	6	17				
	BL 05	3	6	14	16	17		
	BL 06	1	3	15	24	27		
Steering and Control	*SC 01*	2	3	14	27			
	SC 02	3	8	12	14			
	SC 03	3	8	14	22	24		
	SC 04	6	7	14	27			
Drive-Trains	*DT 01*	20	24	25				
	DT 02	20	24					
	DT 03	5	20					
Decks	*DK 01*	40						
	DK 02	14	33					
	DK 03	40						
	DK 04	14	15	40				

Table 6-1: Overall Transformation Models Used in Tech. Evolution of Lawnmower

Transformation Model No.	Frequency									TOTAL Frequency of TM
	MMP	*CLC*	*Transmission*	*CA*	*DC*	*BL*	*SC*	*DT*	*DK*	
1	2	0	2	1	2	2	0	0	0	9
2	2	1	2	0	1	1	1	0	0	8
3	4	4	1	3	3	5	3	0	0	23
4	0	0	1	0	0	0	0	0	0	1
5	2	1	2	1	2	0	0	1	0	9
6	1	0	0	0	2	3	1	0	0	7
7	1	0	2	0	0	0	1	0	0	4
8	0	1	0	0	0	0	2	0	0	3
9	1	0	1	0	0	0	0	0	0	2
10	0	0	0	0	0	0	0	0	0	0
11	0	2	1	0	0	0	0	0	0	3
12	1	0	0	0	0	0	1	0	0	2
13	1	0	0	0	0	0	0	0	0	1
14	3	4	1	0	0	1	4	0	2	15
15	2	5	3	0	2	1	0	0	1	14
16	0	0	0	2	1	1	0	0	0	4
17	1	0	0	0	2	3	0	0	0	6
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0
20	6	0	0	0	0	0	0	3	0	9
21	1	0	0	0	0	0	0	0	0	1
22	0	0	0	0	3	0	1	0	0	4
23	4	0	0	0	0	0	0	0	0	4
24	3	1	4	0	4	1	1	2	0	16
25	1	0	0	0	2	0	0	1	0	4
26	1	1	0	0	0	0	0	0	0	2
27	3	0	0	0	0	1	2	0	0	6
28	3	0	0	0	0	0	0	0	0	3
29	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	2	0	0	0	0	2
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	1	0	0	1	2
34	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0
40	3	0	0	0	1	0	0	0	3	7

Table 6-2: Frequency of Transformation Models Used in Tech. Evolution of Lawnmower



Graph 6-1: Overall frequency of transformation models used in tech. evolution of lawnmower

From the overall frequency distribution of transformation model principles that shaped the technical evolution of the lawnmower, the transformation models that produced the greatest impact on the technical evolution can be clearly identified. These properties can be seen below in table 6-3 as well as their descriptions. These select transformation models are highly likely to be used in future innovations of the lawnmower, and industry should take heed to understand the power and application of these principles.

Rank	Transformation Model No.	Description
1.	Local Quality (#3)	*Local quality* defines the way parts are parts are positioned in a system for operation. A part should always be in an environment where it can offer maximum functionality. This entails designating each part to perform a distinctive and useful function. Often times throughout the innovation process, the placing of parts is not optimal for the system. Relocating these parts to increase their functionality and increase operations has proven to be a major factor in the technical evolution of lawnmowers.
2.	Mediator (#24)	A *mediator* refers to the addition of a new part or an intermediary used to temporarily bring two parts together. The addition of a new part, which evolved the functionality of lawnmowers, is obviously essential in innovation as it applies new technology to replace insufficient ones. The less visible use of the mediator lies in its ability to temporarily connect to things. This was especially evident in the way energy was transferred. Energy is most efficient when used in the shortest path. The use of the mediator in lawnmowers served to shorten the path of energy in most cases making it more efficient, powerful and easier to use.
3.	Spheroidality (#14)	Spheroidality is the use of curves instead of linear designs and applications. Curves hold many advantages to linear application such as increased strength, smooth motion and increase of force in centrifugal applications. Spheroidality can be seen in bearings, rollers, dome shapes and spirals. In the lawnmower, spheroidality was specifically applied to create innovative solutions that reduced friction, increased cutting power, increased deck strength, increase suction power and overall increase usability. The use of spheroidality often allowed one part to gain multiple functions – proof of Law #1, increasing degree of ideality.
4.	Dynamicity (#15)	Dynamicity is the creation of systems that are able to mitigate external changes and dynamics. This can be accomplished through dividing an object into multiple sections that move relative to each other. It also includes the use of suspension systems that mitigate harmful effects an outside environment would otherwise take on the system. Such examples can be seen in the application of flexible connections, which provide a cushioning effect on other components such as belts. This cushioning effect otherwise eliminates the ridged connection of components that otherwise would cause damage to the system.

Table 6-3: Transformation models that produced the greatest impact on the technical evolution of the lawnmower

6.2. Recommendation from Analysis I (Sub-system Evaluation)

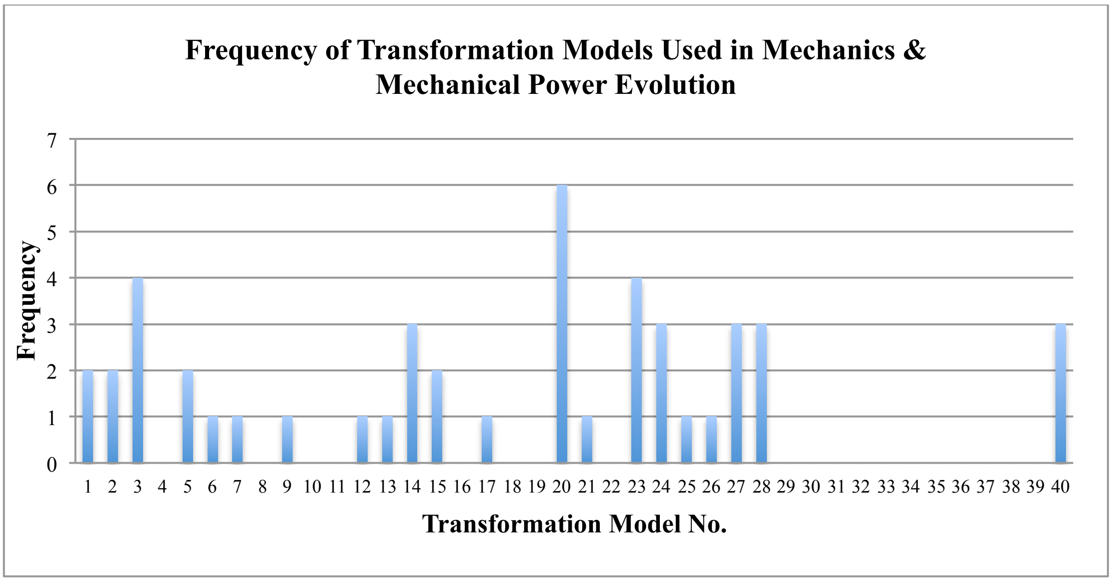
Section 6.2 aims to study the individual results of each sub-system and their resulting transformation model trends. This study utilizes the same principles as above in isolating all the transformation model numbers that evolved the sub-system and plotting their frequency of occurrence. This demonstrates which transformation model principles have the strongest effect on each sub-system, further narrowing down innovation to a modular architecture of components of the lawnmower.

6.2.1. Mechanics and Mechanical Power Evaluation

From the analysis of technological evolution in mechanics and mechanical power (MMP), the summation of transformation models that shaped the MMP subsystem over time can be obtained. These results can be seen in table 6-4 for each innovative step. When combined, the frequency of transformation models used can be extracted from the data resulting in identification of key transformation models that have shaped this system. This can be seen in graph 6-2 below.

Sub-system	***Innovation No.***	**TRIZ Transformation Model No.**						
Mechanics and Mechanical Power	*MMP 01*	13	24	26				
	MMP 02	3	14	24				
	MMP 03	15	20	24	28			
	MMP 04	5	14	27				
	MMP 05	20	27	28				
	MMP 06	3	14	17	20	21	27	
	MMP 07	40						
	MMP 08	2	3	6	12	20		
	MMP 09	20	23	28				
	MMP 10	1	23	40				
	MMP 11	1	2	7	20	23		
	MMP 12	3	5	9	15	23	25	40

Table 6-4: Mechanics and Mechanical Power Transformation Models Used



Graph 6-2: Frequency of transformation models used in MMP

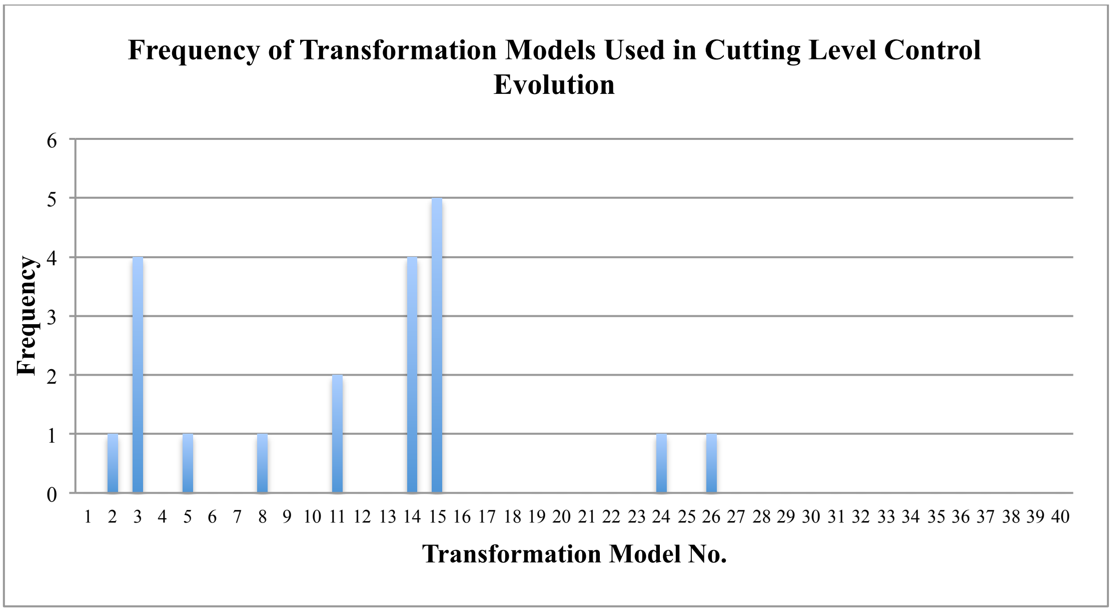
From the frequency chart in graph 6-2, transformation models #20 (Continuity of Useful Action), #3 (Local Quality) and #23 (Feedback) were the most frequently used to advance technology in this system. The principle of "Continuity of Useful Action" was the most frequently used and focuses on optimally using a system at all times by removing idle or intermediate motion in favor of more efficient technology. This can be seen in the moves to more advanced power sources and efficient cutting technology such as engine optimization and battery power, to the application of cutting methods – principally the rotary mower.

6.2.2. Cutting Level Control Evaluation

The cutting level control (CLC) in mowers evolved using the following transformation models seen in table 6-5. The frequency of transformation models used in this subsystem can be seen in graph 6-3 below.

Subsystem	*Innovation No.*	TRIZ Transformation Model No.				
Cutting Level Control	*CLC 01*	8	15	24	26	
	CLC 02	2	3	14	15	
	CLC 03	3	14	15		
	CLC 04	3	11	14	15	
	CLC 05	3	5	11	14	15

Table 6-5: Cutting Level Control (CLC) Transformation Models Used



Graph 6-3: Frequency of transformation models used in CLC

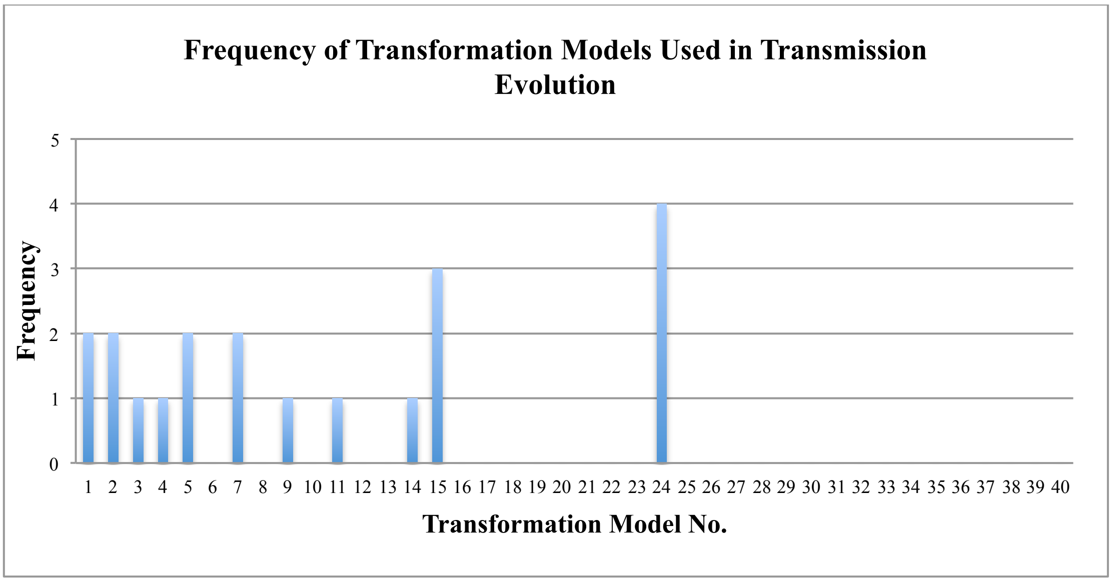
From the table and graph above, transformation models # 15 (Dynamicity), #14 (Spheroidality) and #3 (Local Quality) were the most commonly used principles that contributed to the technological evolution of CLC. Principle #15, Dynamicity, was the most used and deals with the creation of a system that can handle changes from external sources – namely ground height and user control. In this subsystem, the lawnmower must be able to consistently keep its cutting height in relation to the ground. To do so, other principles are used such as #14 spheroidality, the use or round parts and #3 local quality, which uses the optimal placement of components, is widely used.

6.2.3. Transmission Evaluation

The transmission (T) of lawnmowers evolved using the following transformation models seen in table 6-6. Additionally, the frequency of transformation models used in this subsystem can be seen in graph 6-4 below.

Subsystem	*Innovation No.*	TRIZ Transformation Model No.				
Transmission	*T 01*	2	4	15	24	
	T 02	1	3	5	7	
	T 03	2	14	15	24	
	T 04	7	9	11	15	24
	T 05	1	5	24		

Table 6-6: Transformation Models Used in Transmission Tech. Evolution



Graph 6-4: Frequency of transformation models used in Transmissions

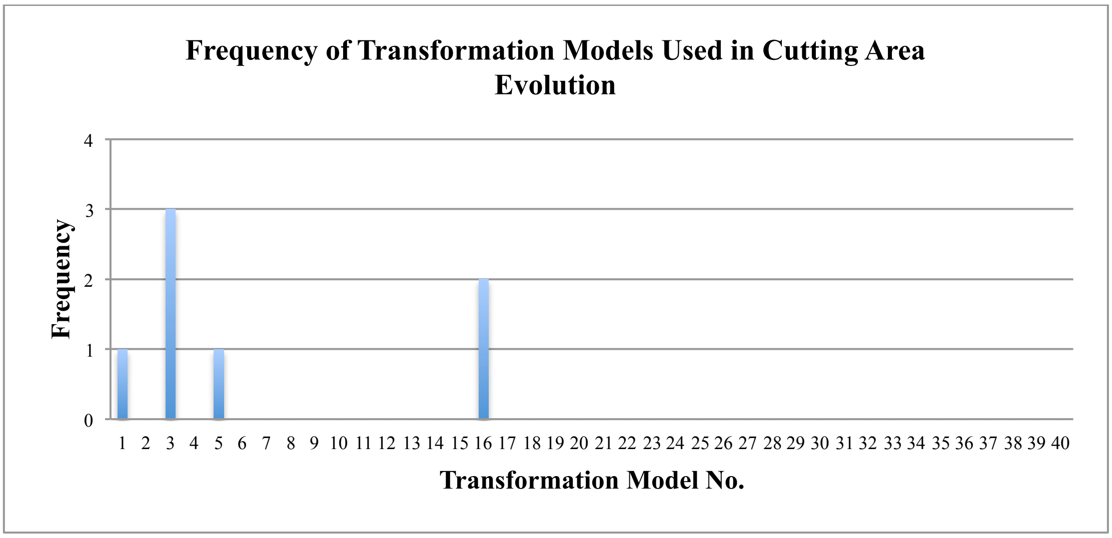
The frequency of transformation models used in the technical evolution of mower transmissions was strongly impacted by principles #24 (Mediator) and #15 (Dynamicity). The principle of using a "mediator" specifically looks at how energy or an action is transferred with solutions of using a new part or applying a temporary object. This can readily be seen in the evolution of solid gearing, to chain drive, to belt drive.

6.2.4. Cutting Area Evaluation

The cutting area (CA) of lawnmowers has evolved using the following transformation models seen in table 6-7. Furthermore, the frequency of transformation models used in this subsystem can be seen in graph 6-4 below.

Subsystem	*Innovation No.*	TRIZ Transformation Model No.		
Cutting Area	*CA 01*	3	16	
	CA 02	3	16	
	CA 03	1	3	5

Table 6-7: Transformation Models Used in Evolution of Cutting Area (CA)



Graph 6-5: Frequency of transformation models used in evolution of cutting area (CA)

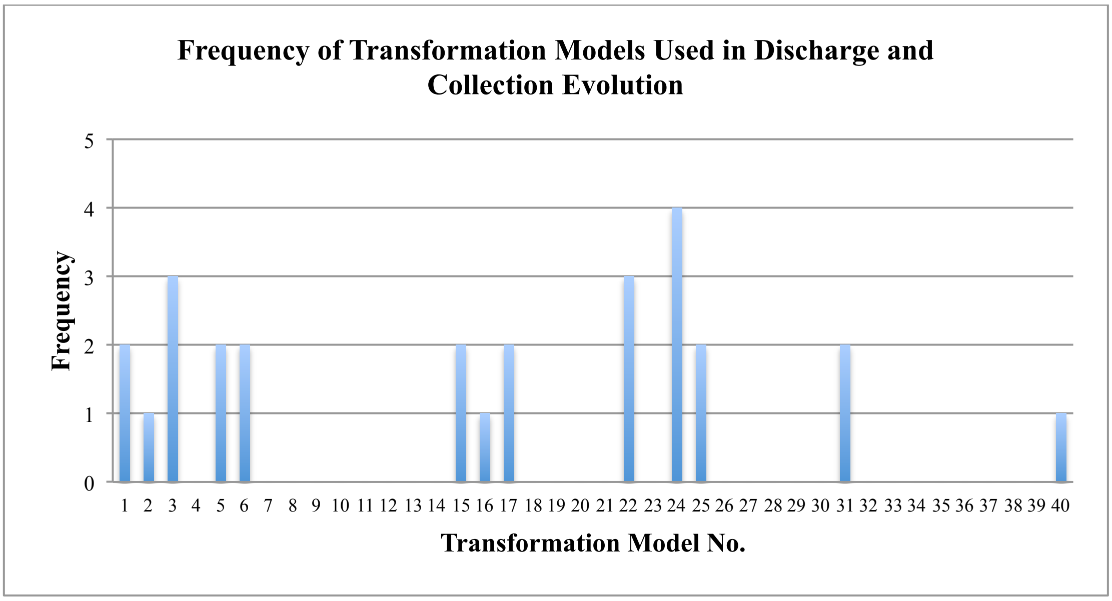
From the extraction of transformation models used in the evolution of the cutting area of lawnmowers, the most influential principle was #3 (Local Quality), followed by #16 (Partial or Excessive Action). Principle #3 is emphasizes the optimization of placing an object in the most useful position and condition for operation. In this case it is optimizing the blade size to achieve maximum cutting area with respect to motor power leading to principle #16, partial or excessive action. Here the mower aims to achieve efficiency while still providing excessive action to cut efficiently

6.2.5. Discharge and Collection Evaluation

The discharge and collection (DC) of grass clippings in lawnmowers evolved using the following transformation models seen in table 6-8. Moreover, the frequency of transformation models used in this subsystem can be seen in graph 6-6 below.

Subsystem	*Innovation No.*	TRIZ Transformation Model No.					
Discharge and Collection	*DC 01*	17	22	24	25		
	DC 02	2	3	6			
	DC 03	17	22	24	25	31	
	DC 04	6	16	22			
	DC 05	40					
	DC 06	1	3	5	15	24	
	DC 07	1	3	5	15	24	31

Table 6-8: Transformation Models Used in Evolution of Discharge and Collection (DC)



Graph 6-6: Frequency of transformation models used in evolution of discharge and collection (DC)

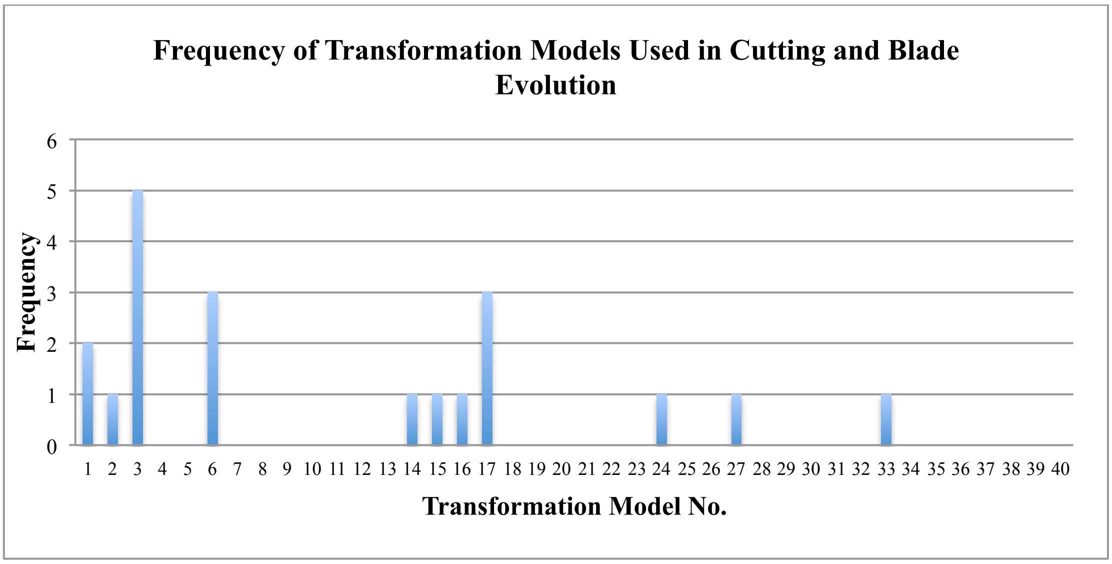
From the results of the transformation model collection for discharge and collection (DC), the frequency and multiple use of certain principles becomes evident. In the evolution of discharge and collection technology, transformation model principles #24 (Mediator), #22 (Convert Harm Into Benefit) and #3 (Local Quality) were the most frequently used. Future innovations in this system will most likely incorporate use of these principles.

6.2.6. Cutting and Blade Evaluation

The cutting and blade (BL) systems evolved in lawnmowers using the following transformation models seen in table 6-9. Additionally, the frequency of transformation models used in this subsystem can be seen in graph 6-7 below.

Subsystem	***Innovation No.***	**TRIZ Transformation Model No.**				
Cutting Technology and Blades	*BL 01*	2	3			
	BL 02	1	33			
	BL 03	3	6	17		
	BL 04	3	6	17		
	BL 05	3	6	14	16	17
	BL 06	1	3	15	24	27

Table 6-9: Transformation Models Used in Evolution of Discharge and Collection (DC)



Graph 6-7: Frequency of transformation models used in evolution of cutting and blades (BL)

From the results of the innovative progress in the technical evolution of cutting and blades (BL), the use of transformation models #3 (Local Quality), #6

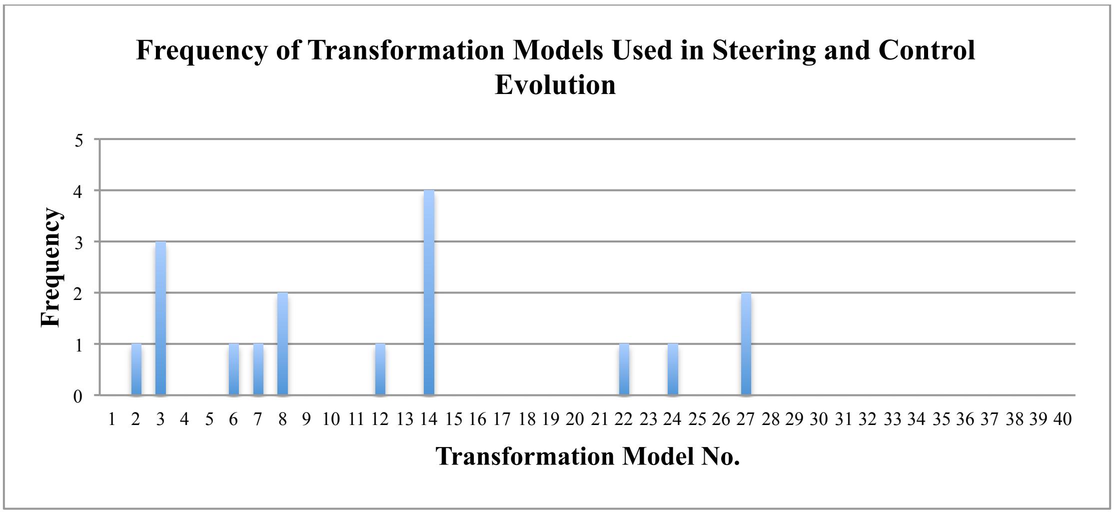
(Universality) and #17 (Transition into new dimension) were most frequently used. These transformation principles are centered on the concepts of placing components in the most effective location, creating components that can perform multiple functions and that reflect energy by transitioning its shape from planar. Future innovations in blade design and technology will most likely use a combination of these extracted transformation models.

6.2.7. Steering and Control Evaluation

The steering and control (SC) of grass clippings in lawnmowers evolved using the following transformation models seen in table 6-10. Moreover, the frequency of transformation models used in this subsystem can be seen in graph 7-8 below.

Category	***Innovation No.***	**TRIZ Transformation Model No.**				
Steering and Control	*SC 01*	2	3	14	27	
	SC 02	3	8	12	14	
	SC 03	3	8	14	22	24
	SC 04	6	7	14	27	

Table 6-10: Transformation Models Used in Evolution of Steering and Control (SC)



Graph 6-8: Frequency of transformation models used in evolution of steering and control (SC)

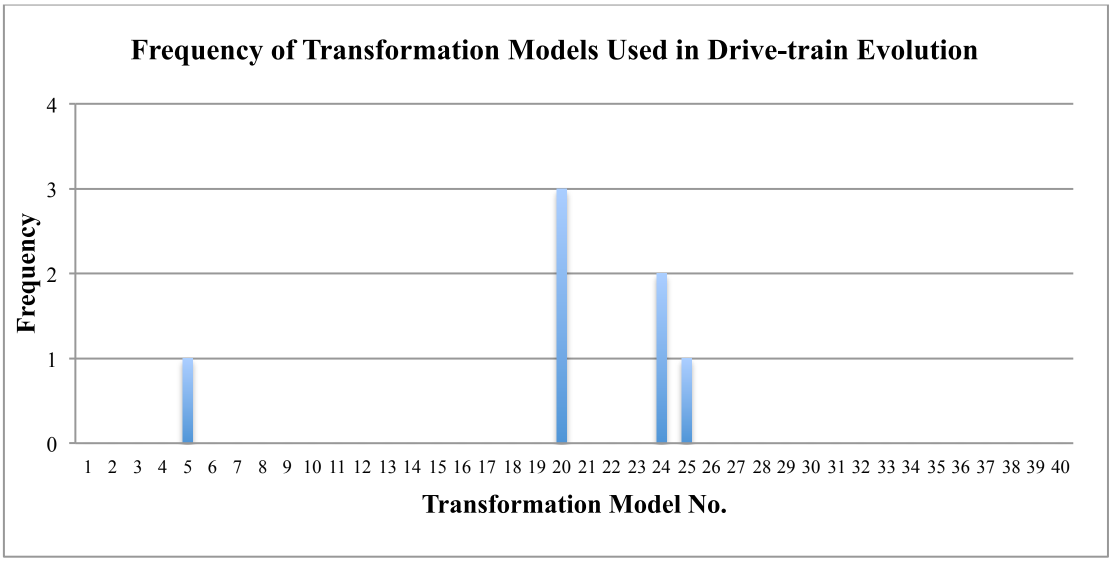
From the extraction of transformation models used in the evolution of steering and control of lawnmowers, the most influential principle was #14 (Spheroidality), followed by #3 (Local Quality). Principle #3 is emphasizes the optimization of placing an object in the most useful position and condition for operation. In this case, it is wheel placement to prevent the crushing of grass, and ease of use. In Principle #14, the diameter of the wheel is often changed for optimal system performance such ease of turning or traction. In future innovations, the transformation models used in table 7-8 will most likely influence future innovations to come in steering and control.

6.2.8. Drive-train Evaluation

The drive-train (DT) in lawnmowers evolved using the following transformation models seen in table 6-11. Moreover, the frequency of transformation models used in this subsystem can be seen in graph 6-9 below.

Category	***Innovation No.***	**TRIZ Transformation Model No.**		
Drive-Trains	*DT 01*	20	24	25
	DT 02	20	24	
	DT 03	5	20	

Table 6-11: Transformation Models Used in Evolution of Drive-trains (DT)



Graph 6-9: Frequency of transformation models used in evolution of drive-trains (DT)

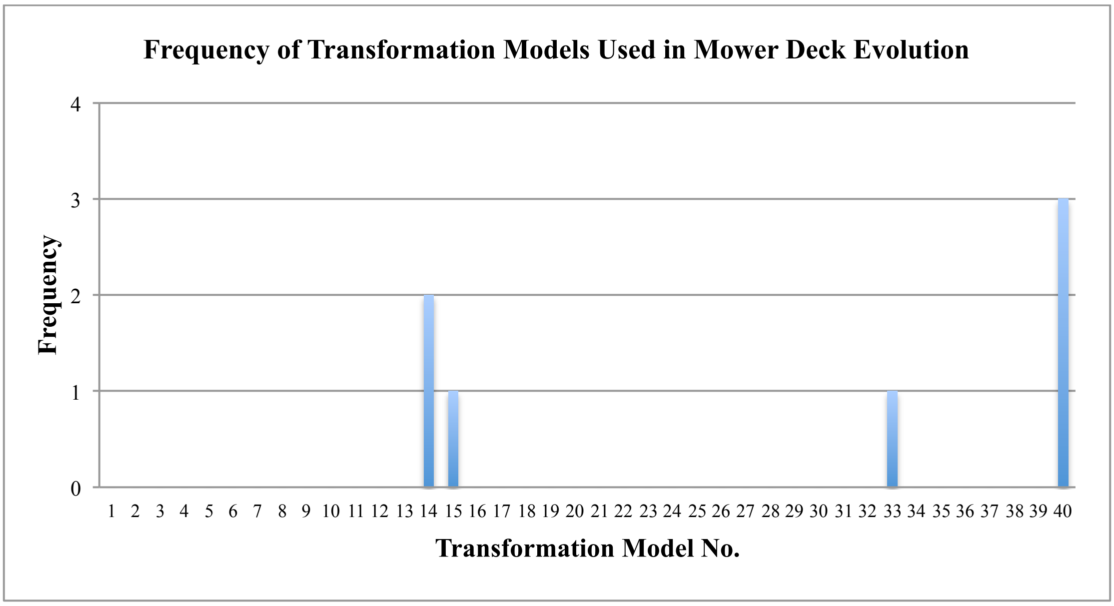
The frequency of transformation models used in the technical evolution of mower drivetrains was strongly impacted by principles #20 (Continuity of useful action) and #24 (Mediator). The principle of continuity of useful action uses the untapped excess power of the engine to perform another function – namely move the mower. The principle of using a "mediator" specifically looks at how energy or an action is transferred with solutions of using a new part or applying a temporary object. This can be seen in the linkage of the motor drive shaft to the drivetrains through belt mediators. Future innovations in mower drivetrain will most likely with the use of transformation principle #20 and #24.

6.2.9. Deck Evaluation

Last the decks (DK) of lawnmowers evolved using the following transformation models seen in table 6-12. Additionally, the frequency of transformation models used in this subsystem can be seen in graph 6-10 below.

Category	Innovation No.	TRIZ Transformation Model No.		
Decks	*DK 01*	40		
	DK 02	14	33	
	DK 03	40		
	DK 04	14	15	40

Table 6-12: Transformation Models Used in Evolution of mower decks (DK)



Graph 6-10: Frequency of transformation models used in deck evolution

The frequency of transformation models used in the technical evolution of mower decks was strongly impacted by principles #40 (Composite Materials) and #14 (Spheroidality). The use of composite materials resulted in decks with lighter weight, increase strength and rust resistant properties that elongating the durability of the lawnmower and increasing ease of use. Spheroidality is the use of curves and is specifically critical to the mower deck as it uses bends to improve strength of the housing when using composite materials. Future innovations of mower decks will most likely with the use of transformation principle #40 and #14.

6.3. Recommendations Analysis II (Technological Forecasting)

The technological forecast using the TRIZ contradiction matrix in Analysis II, is designed to provide insight to present-next generation innovations based off current dominant designs. These recommended transformation model numbers differ from the technological evolution ones as they are designed around specific system contradictions. The technological forecasting was performed through the TRIZ Contradiction Matrix for each subsystem to better predict the direction of technology advancements and their inherent TRIZ solutions. The results show the following transformation models, which will most likely influence near-future innovations of each subsystem, with respect to their given system contradiction and can be seen below in table 6-13. The frequency of these transformation models is not performed due to the specificity of the generated system conflicts for all select subsystems.

Category	**TRIZ Transformation Model No.'s That Will Most Likely Influence Near-Future Innovations per Subsystem**			
Mechanics and Mechanical Power	1	28	7	10
Cutting Level Control	27	35	10	34
Transmissions	10	4	29	15
Cutting Area	15	17	30	26
Discharge and Collection	10	6	2	34
Cutting Technology and Blades	2	27	35	40
Steering and Control	2	13	15	25
Drive-trains	28	10	--	--
Decks	1	8	15	40

Table 6-13: Transformation model No. Solutions to advance current dominant design of lawnmower subsystems using TRIZ Contradiction Matrix

Chapter 7 - Limitations and Further Research

The application of TRIZ in extracting technical evolution is a relative new concept and methodology. TRIZ was first developed in the USSR in 1946 but did not make its way to the Western hemisphere until the late 1990's and early 20th century. Due to this, literature and translated works are few and far between. This research aims to fill in some of the gaps in application of the methodology, and to provide a clear picture of the power TRIZ can have in industry. The limitations of this analysis come in the form of the solutions, which may not be proven correct or otherwise until further industry innovation occurs and analysis of the same method is performed to verify solutions. Additionally, this research was performed by an industry outsider without a TRIZ background. Additionally, the verification of current R&D statuses in the lawn care industry would bring much insight and clarity to further identifying key subsystems and areas of deficiency.

As stated, TRIZ is a moderately new methodology and the research performed only represents a small portion of the full methodology, depth and power of TRIZ. Further applications of the TRIZ method to other areas of technological evolution extraction and forecasting are needed to fortify and strength of the widespread use of TRIZ. Until then, this research stands as a contribution to the already performed works using TRIZ.

Chapter 8 - Conclusion

The results of this research and case study provide a powerful perspective of the importance and significance TRIZ transformation models, in conjunction with technical evolution play in identifying key innovation drivers, as well as projecting future trends. Specifically, the historical study of extracting technical innovation, which resulted in the identification of key TRIZ standardized principles that most influenced technical innovation of the lawnmower and its respective subsystems, could be distinctly defined as seen in table 8-1. These principles, as demonstrated through their frequencies are significant drivers of innovation in each of the subsystems and will likely be used to forward next generation inventions.

Subsystem	***(Analysis I)*** **TRIZ Transformation Model No.'s That Most Influenced Technical Innovation (EXTRACTED METHOD)**			***(Analysis II)*** **TRIZ Transformation Model No.'s That Will Most Likely Influence Near-Future Innovation (CONTRADICTION MATRIX FORECASTING.)**			
Mechanics and Mechanical Power	20	3	23	1	28	7	10
Cutting Level Control	15	3	14	27	35	10	34
Transmissions	24	15		10	4	29	15
Cutting Area	3	16		15	17	30	26
Discharge and Collection	24	3	22	10	6	2	34
Cutting Technology and Blades	3	6	17	2	27	35	40
Steering and Control	14	3	--	2	13	15	25
Drive-trains	20	24	--	28	10	--	--
Decks	40	14	--	1	8	15	40

Table 8-1: Most Influential Transformation Models in Technical Innovation and Future Forecast of Subsystems for lawnmowers

The success in extracting technical innovation using the TRIZ method is novel in the fact that clearly identifies key principles that can be used to forward innovation without relying on trial and error methods and internal experience to produce innovative results - a clear move away from the PDP. The success of this case study in identifying these innovative trends give credence to the TRIZ methodology and the move toward a standardized method of innovation that can more accurately project future trends of technical systems. Moreover, it can allow industries to focus-in on winning designs and efforts that may yield breakthrough solutions further advancing innovative efforts.

The TRIZ methodology to assessing the importance technical evolution plays in projecting future trends is not without benefits and drawbacks. While the extraction of technical evolution resulted in future technical prognostications, it relied heavily on comprehensive knowledge of the technical system as well as access to its historical development, in order to paint an accurate picture of the key drivers of innovation. This resulted in a time consuming process that most companies may be reluctant to make as the data only provided a general overview of which transformation models have been most utilized to provide innovative leaps – not direct solutions to immediate problems.

On the other hand, benefits of the TRIZ methodology to assessing technical evolution can be seen in the clear identification of key transformation models that will most likely influence innovation. This provides a structured approach to addressing innovation of a product and can serve as a guideline for the lifetime and development of a product. As TRIZ is a standardized method, it can consequently be applied to any other industry or product lending to the value of this research.

In all, the TRIZ methodology to extracting technical evolution and using it as a tool to predict future innovative trends is powerful when used in the broad sense to narrow down on winning ideas and identify innovation drivers of a product. Thus said, it cannot not be used to pin-point exact solutions or radically develop technologies at this level, but rather still relies on the creative intuition of its users to elect the final solutions of a products innovative path. In short this research is a valuable aid to understanding the limitations and realizations in using TRIZ transformation models to produce innovative breakthroughs and define future trends of products. While key drivers of innovation can be uncovered, the research shows the methodology still defaults on human creativity to solve problems when used in this capacity. Below is a chart of the benefits and disadvantages of utilizing TRIZ transformation models to extract technological evolution of a product, to identify future innovative trends of systems.

Benefits	**Disadvantages**
• Identification of future innovation trends • Revelation of key transformation models that have most influenced technical innovation of a product • Drastically narrows down which subsystems can combined,	• Time consuming – often with the data being overwhelming • Need compressive knowledge of the system and access to its technical development history to provide a complete picture of its technical development and

eliminated or improved at minimal effort • Provides a short-to-mid-range picture of the next steps a technology will take • Provides key tools to solve innovation complications • Structured methodology lending its application to lifetime or future of product • Applicable to any technological system • Further TRIZ tools can be applied to this method to create a stronger prediction of future trends • This methodology of technical extraction is strong at providing an general overview of the system and its subsystems technical evolution and general direction of future trends • Repeatable for other industries	identify key transformation models • Not often clear which transformation models should be used • Narrows down trajectory of technical evolution but a strong background in engineering is still needed when assessing technical systems • Does not provide a clear picture of long-term technical development • Results may vary with different people • Strong TRIZ background needed • More precise TRIZ tools and analyses are needed to pinpoint clear solutions to overcome modern system conflicts • Correct TRIZ system conflicts must be identified to arrive at correct solutions

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