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Practical Root Cause Analysis Using Cause Mapping

Darren York, Kai Jin, Qing Song, Hua Li

***Abstract*— Failures in global competitive markets have been proved to be costly and sometimes devastate an organization. One way to reduce the loss is to investigate their causes and prevent them from reoccurring. Root Cause Analysis (RCA) is a useful way to achieve this goal. There are three common barriers that need to be overcome in order for RCA to be effectively used. This paper provides an overview of RCA, and applies a commonly used RCA tool, Cause Mapping, in a case study from the refining industry to present the effectiveness of Cause Mapping in eliminating these three barriers. This case study shows that Cause Mapping is an efficient, effective and easy-using method.**

***Index Terms*— Cause Mapping, Quality Control, Refinery, Root Cause Analysis**

I. Introduction

In order to be success with its business, every organization is interested to prevent failure in their operation or products. When a machine or a piece of equipment is out of service, there are always reverse consequences and typically maintenance programs and strategies are designed and implemented to minimize and eliminate downtimes, especially unplanned downtimes. It has been estimated that the typical average downtime cost associated with a standalone machine is $500 per hour, and with the introduction of lean manufacturing strategies, those cost have soared to $1,500 to $8,500 per hour for a cell or line of machines and for an entire auto factory line the estimates skyrockets to $3,500 per minute or $210,000 per hour [1]. The realization quickly comes that such failures can have a profound impact on an organization's competitiveness, especially in the widening global economy.

The cost of such unexpected downtimes provides the necessary incentive to determine the cause(s) and learn from failure in order to prevent them from recurring. However, it must be recognized that money and resources are required to investigate and analyze the failure. Therefore, the real question becomes, "How do you reduce the investment cost in determining the cause(s) of failures?" The main goal is to make easy, fast while reliable investigation, analysis and provide the solution. Root cause analysis is an effective method to achieve this goal. Root cause analysis (RCA) is a systematic, causational analysis which focuses on seeking the lowest level of cause of the failure. There are however three barriers for effective cause analysis that must be overcome to realize this investment reduction. First of all, many of the methods and tools for RCA are complex and difficult to use which in turn makes them less frequently.used, more time consuming and more difficult to propagate throughout the organization to maximize learning from failures. Secondly, many RCA methods or tools require special software applications that foster limited access and an upfront capital investment. Last, some methods or tools require adherence to a very rigid structure thereby limiting creativity and introducing the possibility of missing or short cutting the actual root cause(s).

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Although there are many different types of failures, such as physical accidents or injuries, production errors, procedures not followed, and systems failures, this paper employs equipment failures as the basis of discussion. In this paper, the authors will focus on the Cause Mapping method and discuss a case study from refinery industry in detail. This case study will show that Cause Mapping is an efficient, effective and easy-using method.

II. Review of Root Cause Analysis

Root cause analysis has a wide variety of applications and an extensive history that has generated a considerable list of different tools and methods. The distinction between a tool and a method of RCA might well be, as Gano [2] points out, that "a tool is distinguished by its limited use, while a method may involve many steps and processes and has wide usage." With this distinction and some general categorization, the RCA tools and methods can be more easily understood. Most RCA tools and methods can be categorized into one of the following three categorical types: (1) Charting Types that are constructed in a "flow chart" style form with defined meanings for each shape. Some of these tools and methods are programmatically generated while others can simply be drawn by hand, (2) Tabular Types that are constructed primarily in tables with predefined column headings and categories, and (3) Graphical Types that display data results in a bar graph or some other graphical representation of numeric data. Table 1 details some of the many RCA tools and methods and classify them into the above three categories. Table 1 also shows the evaluation of those methods and tools using the three main barriers to effective usage as the criteria. This evaluation is based on the implementation experiences, literature review, and case study observation.

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TABLE I
Comparison of different RCA methods and tools [1-6]

Method / Tool	Level of Difficulty to Use	Proprietary Software	Creativity Level
CHARTING			
Events & Causal Factors	High	No	Medium
Tree Diagram	Medium	No	Medium
Fault Tree	High	Yes	Low
RealityCharting®	Low	Yes	High
Cause Mapping®	Low	No	High
Fishbone Diagram	Low	No	Low
Affinity Diagram	Low	No	Low
PROACT®	High	Yes	Low
MORT	High	Yes	Low
Relations Diagram	Low	No	Low
Flow Charts	Low	No	Low
TapRooT®	Medium	No	Low
TABULAR			
5-Whys (Why-Why)	Low	No	Low
FMEA	Medium	No	Low
Task Analysis	Low	No	Low
Control Barrier Analysis	Low	No	Low
Change Analysis	Low	No	Low
GRAPHICAL			
Pareto (80/20)	Low	No	Low
Histogram	Low	No	Low

Cause Mapping is the trademarked method of root cause analysis of ThinkReliability and can be categorized as a cause-and-effect chart or diagram. This method does not employ any specific terminology or acronyms and is based on the premise that the "root" is actually a system of causes and not a singular cause [7]. Cause Mapping is based on three fundamental concepts [7]: (1) System Thinking, which means that every system has parts that interact; (2) Cause-and-Effect, which is as stated the cause-and-effect principle meaning every effect has causes and every cause has an effect; and (3) Visual Communication, which indicates the combination of words, images and shapes to communicate the relationships among effects, causes and solutions. Functionally, the Cause Mapping® method consists of three steps: (1) Define the problem, which means simply outlining the what, when, where, and how goals were impacted; (2) Perform the analysis by creating the Cause Map beginning with the impact to goals and working from left to right by asking "why?" and "what is required to produce this effect?" to construct the horizontal and vertical cause and effect relationships as well as documenting and supporting evidence; and (3) Derive the Solutions by determining first "what is possible?", then "what is best?" and lastly by defining the action plan that associates a cause with an action item, assigns ownership and prescribes a due date for completion. The solutions are included in the map with the associated cause as well as in tabular format along with the action item elements. Some of the other recognizable characteristics of a Cause Map, as illustrated by Figure 1, are that it is read from left to right, connects the problem(s) to an organization's goals, and focuses on evidence-based causes.

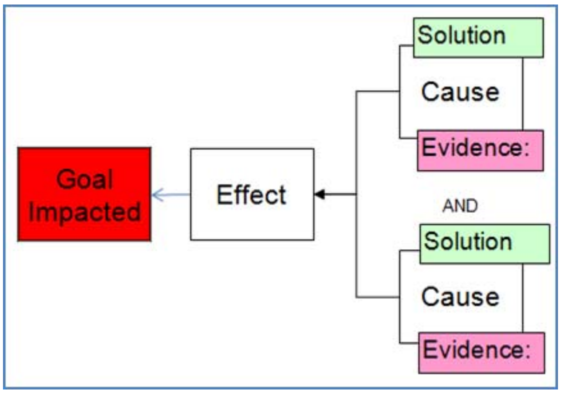

Fig. 1. Cause map structure.

III. CASE STUDY

The case study was undertaken in a United States refinery. The failure to be analyzed is a Crude Vacuum Tower Bottoms Box Cooler that experienced three successive product pass tube failures within a nineteen day period, which resulted in the equipment being removed from service for repairs and requiring logistical feedstock changes to accommodate the box cooler outage. The box cooler functions to cool the crude unit's vacuum tower bottoms (VTB) stream prior to being sent to storage. The box cooler's design is a steel box that contains a series of four pipes, installed inside the box that carries the hot product. The box contains cooling water and the hot product carried in the submerged pipes is cooled as the heat is transferred to the cooling water. The box cooler is also equipped with steam sprayers on each of the four passes to provide heat in the event the product temperature falls below the temperature required to maintain product flow through the passes.

The failures that occurred were holes which developed in the carbon steel piping that carry the product through the box cooler, as shown in Figure 2. The first failure occurred on the third pass and it was isolated and locked out. Two days later, pass four developed a leak and was isolated and locked out. The final failure occurred seventeen days later and it was also isolated and locked out leaving only one pass for VTB cooling. As a result, repairs for the box cooler were planned and executed over an eighteen day outage that cost more than $600,000.

In the first step of RCA, the problems to be analyzed have to be defined. The problem that occurred may impact the factory or organization in different aspects. In this case study, problems were categorized into three different types: (1) Production-Schedule impacts, where the company lost raw material margin on the optimal crude purchase to accommodate vacuum bottoms' minimization during equipment repair outage. (2) Property-Equipment impacts, that the company replaced all four passes, performed patch work on floor, shell and joints. (3) Labor-Time impacts, that the company recruited contract labor and internal labor for the repair work.

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Fig. 2. Holes in the pipes.

The construction of the Cause Map diagram began with the identified impacted goals of production loss, property and labor. The basic level Cause Map was created working from the impacted goals backward to the general event cause by asking five simple "Why" questions similar to the "5-Whys" technique of root cause analysis, as shown in Figure 3.

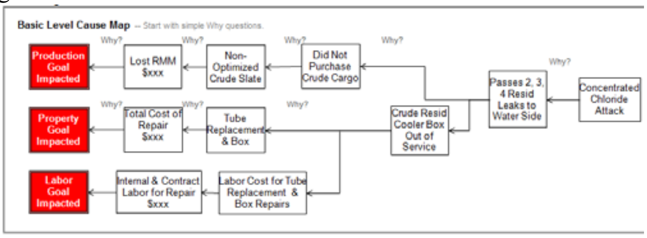

Fig. 3. Basic level cause map

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Based on the preliminary cause map, the detailed Cause Map was then constructed from by asking more "Why" questions and "What is necessary for…" questions to fill in the details between the general elements of the basic map. The evidence and solutions were added to each causal element. The initial version of the Cause Map as developed was subsequently emailed to those interviewed for feedback and then reviewed with the plant reliability manager. Following the reliability manager's suggestion the map was pushed to a deeper level of causation to include all of the corrosion elements for carbon steel submerged in water. The Cause Map was finalized including photos taken during the repair and inspection process along with the action list and the insertion of the electronic copies of the original documents into the Excel file and was shared again with the involved personnel and filed electronically for future reference.

The final problem definition part of the Cause Map of this case study is shown in Table II. We can easily see that unusual failures occurred in a very short period in March 2009, with clear explanation. The economic loss due to the failure summed to $1,634,300. We should be able to save a large amount of money if we can find the root cause to the problem and prevent this happening again.

The coats outside the deepest cause of the problem were stripped off step by step by asking "why". In the end, eight root causes were drawn from the analysis process and the solutions to these eight items were given in Table III.

TABLE II
Detailed problem definition

What	Crude Vacuum Residual Box Cooler Pass Leaks	
When	• March 5, 2009 through March 24, 2009 • Pass 3 leak determined via isolated nitrogen test 3/5/2009. Pass isolated. • Pass 4 leak determined via isolated nitrogen test 3/7/2009. Pass isolated. • Pass 2 leak determined via isolated nitrogen test 3/24/2009. Pass isolated. • Box Cooler removed from service 5/9/2009.	
Where	• Refinery, USA • Crude Unit: Equipment #: XXXX, MFR Serial #: XXXX • Each leak occurred on the bottom row of each pass located on the same side as the inlet and outlet vertical piping on the lower portion of the piping approximately 2' to 3' north of the return bend. • Equipment was in normal operation with no other concurrent activity.	
	Impact to the Goals	**Cost**
Production Schedule	• Potential raw material margin impact due to product contamination with an unplanned shutdown of Mid Crude Unit without cooler box in service or limited to a single pass due to inability to cool slop streams back to crude tanks. • Potential raw material margin impact due to delayed or prevented start up of Mid Crude Unit without cooler box in service or limited to a single pass and downstream unit impacts. • Lost raw material margin on optimal crude purchase to accommodate vacuum bottoms minimization during equipment repair outage.	$912,400
Property, Equip, Mtls	Replace in kind all four passes, perform patch work on floor, shell and joints and install 3/8 inch carbon steel plate under old floor.	$337,500
Labor & Time	Contract Labor and Internal Labor for repair work.	$384,400
	Total Cost	$1,634,300

For the purpose of this study the Cause Mapping root cause analysis method will be evaluated on the three criteria discussed in section 2 and they are the level of difficulty to use, proprietary software required, and creative level. Because the cause mapping method is very easy to implement, the level of difficulty to use ranks low. Cause Mapping does not include unique terminology that needs to be understood in order to effectively apply this method, nor does it include different classifications of causes that can lead to confusion. The overall exercise of conducting the root cause analysis using this method was functionally straightforward and tactically friendly and familiar which lends itself to easy propagation throughout an organization. Since most companies are not willing to pay for outside

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consulting help unless the problem is significant, the best way to analyze problems similar to the one in this case study is with internal resources which are the most familiar with the problem, the systems and the potential solutions. It is important that engineers and those who carry out the RCA can easily master the RCA method with minimal effort and in the shortest time possible. This is crucial, especially in organizations where employees do not have a higher level of education.

TABLE III
Solutions

No.	Action Item	Cause
1	Block in steam spargers and only use if process outlet reaches plugging temperature.	Routine use of Steam Spargers to reduce solid build up on box floor
2	Acid pickle pipe and/or add protective coating.	Retained Mill Scale
3	Establish a blow down program for box cooler and resid pass rotating program.	Concentrated chloride attack and Acidic Pitting Conditions
4	Establish pH and conductivity limits for cooling water quality.	Concentrated chloride attack and Acidic Pitting Conditions
5	1' x 1' patches with 2" rounded corners installed in affected areas.	Box Wall Through Wall Corrosion
6	Cooling Water Inlet Piping replaced with 90◦ angle	Impingement of cooling water inlet pipe due 45◦ angle
7	Box lifted and 3/8 " thick A36 material floor slid under old floor and seal welded.	Underside Corrosion Source
8	Develop 2011 TA repair scope for box cooler including new design and long term solutions to identified causes for box to meet expected TA cycle.	All Causes / Pre-Mature Failure Inside TA Cycle.

With regard to the final two barriers, Cause Mapping does not require the purchase of any proprietary software to fully utilize this method, so there is no upfront capital cost or investment required to employ this method in an organization with complete organizational exposure. The electronic version of choice for Cause Mapping is the use of Microsoft Office's Excel, so most users would already have access to the software required to use the free templates available from ThinkReliability.com. Finally with regard to the creativity level allowed by the investigator and cause map creator, this method allows for complete freedom of expression in creating the map. Cause Mapping does not require the developer to fit cause(s) into prescribed categories and allows for the inclusion of full visual elements such as photos, diagrams, charts to make the map more meaningful and descriptive. The map also allows the developer to directly and visually associate the evidence and solutions with each cause in the map for easy reference and summary understanding.

IV. CONCLUSION

Root cause analysis is a valuable tool that can provide a great deal of knowledge from experience. However, knowledge of causes just for the sake of knowing does not provide value to or for an organization. Sondalini [8] concludes, "We need to flavor RCA with a new purpose if we are to use it effectively in industry. We must refocus our aim for RCA to one of business-wide improvement and not single problem-solving." This view of RCA along with the concept of Enterprise Knowledge Management introduced by Cormican and O'Sullivan [9] hold great promise for the organizations to take their performance to the next level and become even more competitive and efficient. Cause Mapping as demonstrated in this paper is an effective and practical root cause analysis method that can be easily and successfully employed in an organization without the expenditure of capital funds for proprietary software and still provide tremendous freedom within the analysis method and thus overcomes the three barriers to effective root cause analysis. As such, Cause Mapping fits well into the space of today's view of root cause analysis as well as adaptively fitting the views of root cause analysis and enterprise knowledge management of the future.

One of the unanticipated strengths of Cause Mapping comes from Excel. Using the Excel template, a cause map can become a sustained knowledge system for an organization. In the electronic version the map can be the repository for all the supporting documentation from an event. This easy reference capability provides for fast and easy access to the "value" of the experience. According to [5], "Contemporary business systems have become more knowledge intensive and this specialization of work leads to an increasing need for knowledge workers." Cause Maps have the potential to become a business system that facilitates the development of these knowledge workers. One particular element of a Cause Map that makes it possible is one of the method's greatest strengths – visualization. The map with its full feature presentation allows for a quick and thorough understanding of the events, the lessons learned, the solutions employed and possible extensions to similar situations through its visual elements. The Cause Map, because of these visual elements, truly becomes the map for an organization from failure to success.

From the same element of creativity springs the largest weakness of the method. Cause Mapping, inclusive of all its creative capabilities is limited by the developers experience with root cause analysis and investigative methods. To the extent that an organization has good problem solvers, Cause Mapping could be used organizationally with great results. For those organizations with a lack of experience in problem solving, the implementation time to value realized curve would mostly likely be somewhat exponential in shape. Notwithstanding for these organizations, coupling problem solving and investigative methods training with Cause Mapping would no doubt achieve satisfactory results.

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