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CASE STUDY IN HYPOTHESIS PRIORITIZATION WITH ISHIKAWA DIAGRAMS

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Abstract:
The objective of this paper is to explore a multidisciplinary problem-solving team investigating a customer-reported failure using an Ishikawa diagram with a spreadsheet for prioritizing and tracking investigation actions in a manufacturing organization. A case study methodology is used with the actions taken to investigate a customer-reported failure explained. The highest priority failure hypothesis was found to be unrelated to the failure. Two medium-rated hypotheses were found to be causing the problem; leakage was occurring at the connection between two components due to a diameter deviation of one of the components. Identifying and prioritizing hypotheses from the Ishikawa diagram provided structure to the investigation and gave the investigation team leader a tool for tracking the investigation actions. This approach is suitable for all types of failure investigations in which an Ishikawa diagram is used to list hypotheses.

Key words: *Root Cause Analysis, RCA, Problem-Solving, Quality, Case Study*

INTRODUCTION

When quality failures happen, the root cause of the failure must be found to ensure the failure can't happen again by implementing actions to prevent a reoccurrence of the failure [1]. An RCA is a "structured approach that identifies factors resulting in the problem outcome" [2 p. 538] and can be performed for many different types of problems [3].
Quality failures that require an RCA include assembly problems such as a door panel that does not properly align [4] or a fan with an unwanted humming noise [5], a component with cracks or burrs [6], or a process failure such as long delays in a service [7]. An RCA may also be performed to identify the causes of accidents [8] or medication errors in hospitals [9]. Once identified, possible failure causes must be evaluated by comparing the hypothesized cause to both the problem statement and data [10].
To find a root cause, an Ishikawa diagram is often used to list potential causes that can be investigated [11]. However, it is often not possible or practical to investigate all hypotheses at once; therefore, hypotheses must be selected for investigation. The hypothesis should be selected in consideration of how easy the hypothesis is to evaluate together with how likely the hypothesis is to be correct [12].
A case study presented in this paper describes an organization's use of an Ishikawa diagram to investigate the failure of a manufactured product. Hypotheses to explain the failure were generated and listed in the Ishikawa diagram. The hypotheses from the Ishikawa diagram were transferred to a spreadsheet and prioritized with the prioritization based on consideration of how well the hypothesis fit the available evidence. The use of a spreadsheet with prioritization for actions to investigate hypotheses from an Ishikawa diagram has not been previously explored in the literature. The use of such a spreadsheet has been briefly described in the literature; however, this paper provides a first case study in such an approach.

LITERATURE REVIEW

An RCA requires a structured approach [13] and there is a wide range of structured methodologies that can be used to support RCA. The 8D report is a common methodology for performing an RCA [14]. Another common problem solving method is the A3 report [15]. Although traditionally used for quality improvement, Six Sigma can also be used for RCA [16]. A simpler methodology, such as PDCA (Plan Do Check Act), also known as PDSA (Plan Do Study Act), can be used as a process for performing RCA [17].
There are commonalities across RCA methodologies. According to Smith, there must be information must be collected, the information must be interpreted, hypotheses need to be generated, and then the hypotheses must be evaluated [18]. Regardless of methodology, there is generally a need to define the problem, analyze the problem, identify and evaluate solutions to the problem, then select

and implement a solution to the problem [19]. An RCA also requires a multidisciplinary team with knowledge of both the problem and quality. The team must brainstorm possible failure causes [20]. Hypotheses are formed using a combination of observations and dominion knowledge [21].

There are many quality tools that can be used during an RCA such as the Ishikawa diagram, histogram, Pareto chart, check sheet, and scatter plot [22]. One of the most commonly used quality tools for RCA is the Ishikawa diagram, which is "a tried-and-tested method" [23 p. 31] and is also known as a cause and effect diagram or a fishbone diagram) [24].

The Ishikawa diagram may be used with other quality tools, such as five whys. This is because the failure causes identified by an Ishikawa diagram may have their own causes, which require further investigation to get to the root cause. Finlow-Bates presents the case of a tanker ship blown into rocks because a weld on a rack had a weak spot that resulted in the rack breaking and releasing pipes that damaged a ventilation pipe that let in water resulting in contamination of the ship's fuel. This led to the loss of a heater causing the fuel to get too cold and viscous causing the loss of the ship's engine. Without engine power, the ship was blown onto rocks [25]. To create an Ishikawa diagram, the failure is listed in front of a horizontal arrow. Angled arrows point toward the horizontal arrow and these are the main branches and each has a label. The main branches have smaller horizontal arrows as sub-branches listing hypotheses [26]. The problem-solving team would then brainstorms potential causes that would be listed under each category in the Ishikawa diagram [27].

Ahammed and Hasan used an Ishikawa diagram in a Six Sigma project with the branch names consisting of material, machine, man, method, environment, and measurement [28]. Kumar and Adaveesh use the branch names machine, method, man, material and measurement [29]. Darekar et al. use the branch names material, man, measurement, and method with material referring to inputs, man referring to lapses, measurements pertaining to testing and assembly, and method referring to assembly [30]. Zarghami and Benbow use mother nature, measurement, manual, machine, methods, and materials (2017) [31]. Alternatively, some authors deviate completely from the concept of 6Ms. For example, inspection, heat treatment, tools, and process [32].

Specific hypotheses are listed on sub-branches under the main branches of an Ishikawa diagram. For example, Mahto and Kumar list maintenance under the top branch machinery and inadequate maintenance and lack of preventative maintenance as lowest-level branches [33] and Anderson and Kovach list pipe under the material branch with the lowest-level branches consisting of magnetism, thickness, wrong windbreaks, and diameter [34] and Gijo and Perumallu use procedures, work instructions, fixtures, and handling toehold as sub-branches under the main branch method [35]. Even Ishikawa himself used different labels, such as assembly, F resistor, inspection, G resistor, and tools in one Ishikawa diagram and materials, workers, tools, and inspection in a different Ishikawa diagram [36]. In addition, there is also variation in the name used for an Ishikawa diagram. For example, an Ishikawa diagram is also known as a cause and effect diagram, or a fishbone diagram [37].

Many hypotheses may be listed in an Ishikawa diagram. However, only the hypotheses that have the highest probability should be evaluated [38]. The hypotheses are evaluated and rejected if they are not supported and then a new hypothesis is evaluated. Listing many possible failure causes and evaluating them is a funneling strategy, which can be successful when there are few potential causes. However, too much effort may be required when there are many hypothesized causes [39]. Smith suggests selecting 3 to 5 hypotheses for evaluation [40]. Hypotheses listed in the Ishikawa diagram can be color-coded to indicate the degree of importance of each hypothesis [41]. A worksheet for prioritizing actions to investigate and a tracking sheet for prioritizing has been proposed by Barsalou. Such a worksheet is called a Perkin tracker and would list the hypotheses from the Ishikawa diagram as well as actions to investigate the hypothesis, a person responsible, a target completion date, and a conclusion. The worksheet also has a column for prioritizing hypotheses to investigate using low, medium, and high levels [42] as shown in Table 1.

Table 1
Perkin tracker reproduced from © Barsalou 2016. Used with permission

Perkin Tracker
Issue Name:
Created by:
Status Date:

Ishikawa Item	Priority	Action to Evaluate Hypothesis	Responsible	Target	Root Cause?	Conclusion
Material: Wring material used (Incorrect material was not sufficient for the usage)	High	Ensure material is per drawing 75646e	B. Gadison	18 March 2016	Yes	The material used was not the type of material specified on the drawing
Material: Wrong turning speed (High turning High speed damaged surface)	Medium	Check material specification to ensure material meets requirements	A. Ethridge	22 March 2016	No	Material on the drawing is robust to operating conditions
Machine: Wrong turning speed (High turning speed damaged surface)	High	Check parts for signs of wrong turning speed	D. Fulton	31 March 2016	No	No sign of wrong turning speed
Machine: Clamping damage (Clamping damage pre-weakened part)	Low	0	0	0		0

The Ishikawa diagram is frequently used during an RCA to uncover the root cause of a failure. As explained in this literature review, there is variation between authors on both names for Ishikawa diagrams and the labels used on branches in the Ishikawa diagram. Other names for the Ishikawa diagram consist of the cause and effect diagram and the fishbone diagram. Although Ishikawa diagrams often use branch labels consisting of the six Ms, authors also use problem-specific branch labels in their Ishikawa diagrams. The hypotheses listed in the Ishikawa diagram need to be investigated, and this can be assisted by using a Perkin tracker to list and prioritize actions to investigate, as well as to track the investigation actions.

METHODOLOGY

This paper uses a case study approach, which is a type of qualitative research where an issues, such as an event or situation, is explored to gain an understanding [43]. The case study method was selected as it is a suitable form of research for situations in which the researcher has no control [44]. In this case study an organization used a Perkin tracker-like spreadsheet together with an Ishikawa diagram to investigate quality failures. The exact names of the components used have been changed to obscure the identity of the organization.

The problem under investigation started when a customer reported 8 units were failing the system level check at their facility; although more were requested, only two units were returned. They were tested and one was found to be much worse than the other. These were not just random samples of the failed units; the customer had sent the best and worst performing units so there was much contrast in how well they did even though both were failing. The customer had also swapped out parts between the various complete systems and had found that the problem followed Component D. This simplified the investigation as the problem was localized to one part; this part was, however, an assembly with Assembly B welded to it and Assembly B had a pipe attached to it. Together, the parts of Assembly B functioned as a petcock.

RESULTS

A cross-functional team was formed and an Ishikawa diagram was created once the problem was understood and quantified. The team was led by the component engineer and heavily supported by a quality engineer. The project manager was nominated as the team champion and additional members consisted of several quality engineers, a computer simulation engineer, a reliability and testing engineer, an analysis technician, and an expert in system levels.

A simplified version of the problem statement was then listed as the effect under consideration in the Ishikawa diagram. The team included representatives from various departments and they felt that they had a thorough understanding of both the product and the test system where it failed, so they decided against using the more traditional six Ms of an Ishikawa diagram. As shown in the literature review, many authors, including Ishikawa himself, used problem specific branch names in place of the six Ms. The main branches they decided to use were component A for production and assembly failures related to component A, component D side for the many things which could have gone wrong on component D side, complete system, process to encompass various potential manufacturing or assembly failures, and external to cover anything that may have happened on the customer side. The resulting Ishikawa diagram is shown in Figure 1.

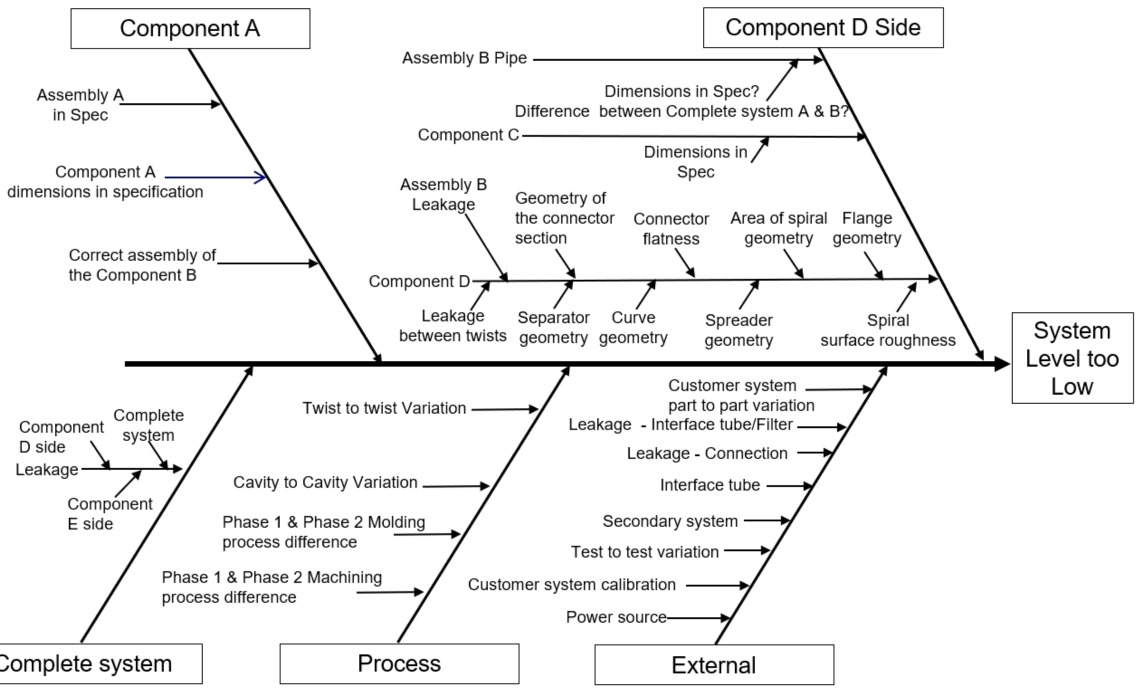

Fig. 1 Ishikawa diagram for system level too low

A heavy emphasis was put on Component D when creating the Ishikawa diagram because it had already been proven to be related to the problem. For this reason, Component D was used as a main branch in the Ishikawa. One specific part was shown to be related to the problem; however, the team did not want to risk becoming overly fixated on that one part. Component A was also used as a main branch in the Ishikawa because a problem in Component A could theoretically cause the failure; this assessment was based on the team member's knowledge of the product and prior experience. Although Component D was related to the failure, it may have been affected by outside influences, so additional branches were process, complete system, and external, which included the customer's system and test station.

The Ishikawa diagram was completed in a team meeting with the quality engineer serving as a moderator and methodology expert. The technical experts were needed to contribute their inputs and the moderator facilitated this and addressed any methodology-related questions members of the team may have had. According to Doggett, a weakness of the Ishikawa diagram is that the relationship between items in the Ishikawa diagram and the failure may not be clear [45], to counter this problem, the team would investigate the Ishikawa diagram items.

Once an Ishikawa diagram was completed, the team needed to determine which hypotheses would be investigated as well as how they would be investigated and who would perform the investigations. There were insufficient resources to evaluate every hypothesis at the same time so the team decided that the hypotheses needed to be prioritized and they used three levels of prioritization; low, medium, and high.

The inputs of the completed Ishikawa diagram were then transferred into a spreadsheet with one column listing the main Ishikawa branch and a second column showing the lower-level branch as a hypothesis. A new meeting was then held to prioritize the investigation of the hypotheses using the three levels of prioritization were used.

Hypotheses rated as high were strongly suspected to be related to the failure or very easy to check. Those rated medium were believed to be less likely to cause the failure or were either too difficult or too expensive to quickly check. A low rating was given to any hypothesis that could have theoretically caused the failure, but the team did not believe it to be the cause in this situation. Costs were an additional consideration; had there been a significant difference in costs, the team would have downgraded an expensive higher priority hypothesis to medium and upgraded a lower cost medium priority to high.

Actions were first assigned to the two high-priority items. Then medium priority items were then assigned actions to investigate them. In this case, the high-priority hypotheses were prioritized for actions before lower-ranked hypotheses, but the actions required more time to complete. Therefore, there was sufficient capacity to investigate medium and low hypotheses in parallel.

Each action item was assigned a responsible person and a due date. Some actions, such as performing a leakage measurement in the lab, were to be performed by people outside of the root cause analysis team. In such cases, a team member was assigned responsibility for informing the correct person and bringing the results back to the team. This ensured that the team leader had a dedicated single point of contact for each action item; the responsible person would be the one whom the team leader could ask for status reports and who would bring results back to the team. The resulting spreadsheet is shown in Table 2.

Table 2
Ishikawa action item worksheet

Ishikawa Branch	Hypothesis	Prio.	Responsible Person	Actions to Take	Due	Description of Results	Results
Process	Twist to twist Variation	Medium	C. Hubbard	3D scans of delivered TH	30 Oct.	No significant differences between parts	OK
Process	Cavity to Cavity variation	Low	D. Goodwin	Analysis with supplier	30 Oct.	No significant differences between parts	OK
Process	Phase 1 & Phase 2 Molding process difference	Medium	J. Reese	Analysis with supplier	30 Oct.	No indication of contribution to the failure	OK
Process	Phase 1 & Phase 2 Machining process difference	Low	J. Reese	Analysis with supplier	30 Oct.	No indication of contribution to the failure	OK
Complete System	Complete system	Medium	S. Barton	Leakage measurement in Lab	06. Nov.	No indication of contribution to the failure	OK
Complete System	Component D side Leakage	Medium	S. Barton	Leakage measurement in Lab	06. Nov.	Huge influence of component D leakage on failure	n.OK
Complete System	Component E side Leakage	Medium	S. Barton	Leakage measurement in Lab	30 Oct.	No indication of contribution to the failure	OK
Component D Side	Assembly B Pipe: Dimensions in Spec?	Medium	S. Barton	Leakage measurement in Lab	30 Oct.	Huge influence of leakage at assembly B on the failure	n.OK

Table 2 cont.

Ishikawa Branch	Hypothesis	Prio.	Responsible Person	Actions to Take	Due	Description of Results	Results
Component D Side	Component C: Dimensions in Spec?	Medium	C. Hubbard	Measurement Lab analyzing dimensions	13. Nov.	No significant differences between "good" and "bad" parts	OK
Component D Side	Component D: Assembly B Leakage	High	V. Ferguson	Measurement Lab analyzing dimensions	28. Nov.	No significant differences between "good" and "bad" parts	OK
Component D Side	Component D: Geometry of the connector section	Medium	J. Morgan	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Connector flatness	Medium	D. Goodwin	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Area of spiral geometry	Low	D. Goodwin	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Flange geometry	Medium	D. Goodwin	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Leakage between twists	High	J. Reese	Check against specification and good parts	28. Nov.	In specification and comparableto good parts	OK
Component D Side	Component D: Separator geometry	Low	D. Goodwin	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Curve geometry	Medium	D. Goodwin	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Spreader geometry	Low	J. Reese	Check against specification and good parts	28. Nov.	In specification and comparable to good parts	OK
Component D Side	Component D: Spiral surface roughness	Low	J. Reese	Measurement of spiral surface roughness	4 Dec.	No significant differences between "good" and "bad" parts	OK
Component A	Assembly A in Spec	Low	C. Lopez	Skipped - No indication of influence on failure	n/a	0	0
Component A	Component A dimensions in specification	Low	C. Lopez	Skipped - No indication of influence on failure	n/a	0	0
Component A	Correct assembly of the Component B	Low	C. Lopez	Skipped - No indication of influence on failure	n/a	0	0
External	Customer system part to part variation	Medium	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" parts	OK
External	Leakage - Connection	Low	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" parts	OK
External	Interface tube	Low	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" parts	OK
External	Air Inlet/Outlet Piping	Low	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" parts	OK
External	Secondary system	Low	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" parts	OK
External	Test to test variation	Low	M. Fletcher	To be confirmed by customer	7 Dec.	System tested on the same customer system and test station	OK
External	Customer system calibration	Low	M. Fletcher	To be confirmed by customer	7 Dec.	No influence detected	OK
External	Power source	Low	M. Fletcher	To be confirmed by customer	7 Dec.	Identical environment for "good" and "bad" turbos	OK

Unexpectedly, the highest priority hypotheses turned out to be unrelated to the cause of the failure. Although unexpected, it was not critical as additional actions had already been planned. The team continued the investigation and two medium-priority hypotheses turned out to be related to the problem; component D side leakage and Assembly pipe B dimensions were the root cause. Component D side leakage was a vague hypothesis and would have required further investigation to determine exactly what characteristic was relevant; however, the problem was quickly localized to assembly pipe B dimensions. Although component D side was vague, it was sufficient because there would be no need to for the team to find underlying causes for a component side D problem if it was found to be OK.

The team could “turn the problem on and off” once a specific part and dimension were identified as the root cause. They would switch out bad parts with good parts and the problem would follow the bad part. They could later also predict which complete systems would fail using

component A pipe dimensions; thereby generating confidence in the identified root cause.
The team decided to use three levels of color coding in the Ishikawa diagram to quickly communicate prioritization to both the customer and their own management. These were based on the prioritizations in the spreadsheet and the updated Ishikawa diagram is shown in Figure 2 with color coding replaced by font type for better visibility in black and white. This was intended to help streamline meetings when presenting the investigation.

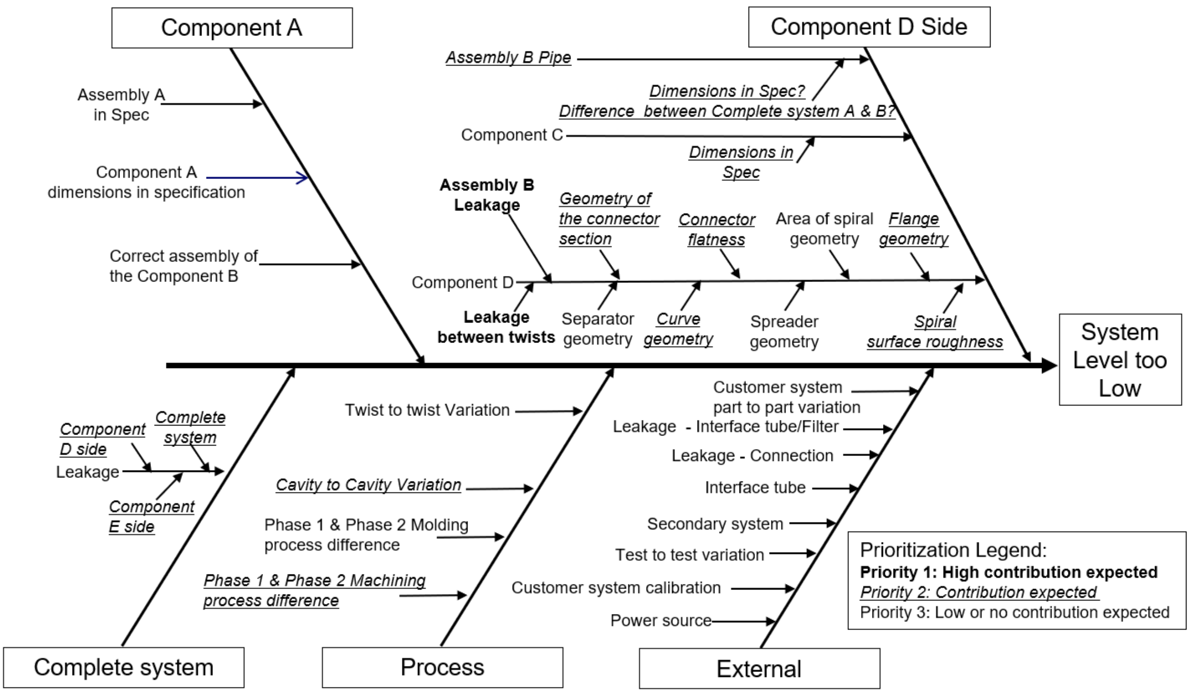

Fig. 2 Ishikawa showing prioritizations

A problem-solving team used the Ishikawa diagram to investigate the failure of 8 units at their facility, as well as additional failures at the customer. Explanatory hypotheses were formed by a cross-functional team and listed in the Ishikawa diagram. The hypotheses from the Ishikawa diagram were transferred to a spreadsheet and prioritized as high, medium, and low. People were then assigned reasonability for carrying out investigation related tasks to investigation. The root cause was found and verified by "turning the problem on and off."

DISCUSSION

The problem-solving team faced a potentially crucial problem due to the customer's refusal to return failing units; however, the two that were returned were sufficient for identifying the root cause, which would not have been possible without investigating the two failed units.
The team had some confidence that they understood what the root cause was and the top hypotheses were identified as a high priority in the Perkin tracker. The high-priority hypotheses were prioritized to be investigated first, but the investigation actions needed time to complete; therefore, medium and low-priority hypotheses were assigned actions to be carried out in parallel. This situation demonstrates how there can be occasions when high-priority hypotheses are evaluated after lower-priority items such as when parts are not available due to lead time or an outside resource lacks capacity. For problems such as capacity, the team champion would be informed so that they can escalate to a higher management level to attempt to free up resources, if possible. In this situation, the nature of the evaluation was what led to a delay.
High-priority hypotheses would have been investigated first if there had there been a resource or capacity conflict between high and medium-priority actions. Low-priority hypotheses would have been considered once high and medium-priority hypotheses had been assigned an investigation action.
Although the problem-solving team started the investigation confident they knew what the root cause was, assembly B leakage due to flange geometry, a careful investigation showed that they were incorrect. This demonstrated the need to investigate, even when a root cause is thought to be known.
This paper has an implication for managers. Managers should require the use of an Ishikawa diagram supplemented by an Ishikawa diagram action item tracker in the form of a Perkin tracker when teams are performing an RCA.

CONCLUSION

An Ishikawa diagram is a commonly used quality tool that has been around for decades [46], but it is not too late to further expand upon this tool. The use of a Perkin tracker or spreadsheet for prioritizing and tracking action items related to the root cause investigation has also been described in this paper. This paper is the first case study describing the use of a Perkin tracker for an actual failure investigation and can serve as a guide for other organizations using an Ishikawa diagram with a Perkin tracker. A limitation of this paper is that the case study only covered one failure investigation in one manufacturing organization. An opportunity for future research would be to study the use of an Ishikawa diagram with a Perkin tracker in a service organization.

The case study demonstrated that modifying the Ishikawa diagram's category names made it possible to list hypotheses under product-specific category names and the use of a spreadsheet provides a method for prioritizing and tracking actions. However, the addition of a method for prioritization can be helpful when the team must consider the strength of a hypothesis in regards to the available evidence, the cost to investigate the hypothesis, and the effort required to investigate the hypothesis. The identification of the strength of evidence, cost, and effort-based prioritization criteria can serve as a basis for future research.

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