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Supply Chain Disruptions Mitigation Plan Using Six Sigma Method for Sustainable Technology Infrastructure

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Abstract
Supply Chain Management (SCM) is a very important part of the industrial world, especially in the manufacturing sector. The development of the business world affects the complexity of the supply chain due to the lack of logistics infrastructure, quality of materials and components, and much more. Supply chain disruption risk mapping needs to be done due to high uncertainty, which is overcome by implementing a decision support system. Based on the background of the problem, supply chain disruption mapping uses the help of the Six Sigma method, which consists of 5 stages: Define, Measure, Analyze, Improve, and Control (DMAIC). The measurement of disturbance also uses the Failure Mode and Effect Analysis (FMEA) approach to prioritize risk. Risks that have a high assessment and cause failure need to be prioritized for improvement. This study aims to map supply chain disruptions in the current manufacturing industry based on the barriers, resistances, and causes detected for making a decision support system prototype. By implementing a decision support system in the supply chain process, it is hoped that the manufacturing industry can minimize potential losses from existing risks.

Keywords
Supply Chain Management, Six Sigma, FMEA, Decision Support System.

Introduction

Supply Chain Management (SCM) is a very important part of the industrial world because it delivers a product from the producer to the final consumer (Hofmann et al., 2019). The supply chain is considered several business components that integrate the relationships between suppliers, manufacturers, distributors, and retailers. The supply chain flow process in an industry generally starts from obtaining raw materials for production (upstream). Raw materials that have been received are then processed and produced into finished materials (internal). The final stage focuses on distributing finished products to consumers through distributors (downstream) (Tarigan et al., 2021). The business world's development will affect the supply chain in each industrial sector. The stability of the supply chain can affect the performance of the process. One of the causes of supply chain instability is the occurrence of disturbances. Some of the complexities of supply chain processes today cause problems of uncertainty in delivery times, quality of materials and components, and do not have their own logistics infrastructure. Difficult supply chain processes have affected the financial and services of the industry.

The manufacturing industry needs to improve the financial and service aspects of the supply chain process by implementing an information technology-based system (Dehgani & Navimipour, 2019). Technology development and adaptation to welcome innovation is very important to create sustainable competitiveness as a decision support system. The application of a decision support system can solve customer problems faster, increase sales volume, and take advantage of markets that are not accessible due to constraints. A strategic planning decision support system can support decision-making on changing market needs. Therefore, mapping supply chain processes in the manufacturing industry need to discover what problems or disturbances are currently experienced (Ivanov & Dolgui, 2021). By mapping the current sup-

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ply chain disruption risk, it can be used as a basis for considering a decision support system.

The emergence of the risk of supply chain disruption in the manufacturing industry is due to high uncertainty. Every supply chain activity process has the potential to face the risk of disruption. The risks that arise in the manufacturing industry are classified as internal (problems with management decisions) and external (problems from suppliers and consumers) (Paksoy et al., 2019). Some examples of supply chain disruption risks in the manufacturing industry include raw material shortages, supplier failures, rising material prices, machine breakdowns, uncertain demand, inaccurate forecasts, order changes, and transportation failures. Generally, the manufacturing industry has implemented standards in many ways. However, in an uncertain business environment, actual results do not always match performance standards. The variance identified as disruption risk is the difference between actual results and existing supply chain standards. Productivity and supply chain efficiency needs to be improved by mapping out the current disruptions in the manufacturing industry (Bui et al., 2021).

Based on the background of the problems described previously, a mapping of the current supply chain disruptions is needed to reduce the negative impact on the performance of the manufacturing industry. Mapping supply chain disturbances using the help of the Six Sigma method, which consists of 5 stages (Mubarik et al., 2021). Disruption mapping starts from determining the problem by identifying supply chain performance disruptions in the marketing, finance, and production processes. After getting the current supply chain disruption, it is continued with measurements using the Failure Mode and Effect Analysis (FMEA) approach. FMEA helps calculate accuracy for risk prioritization (Bhattacharjee et al., 2020). Furthermore, supply chain risk is evaluated to determine whether the disruption experienced affects the manufacturing industry's time, quality, and cost. Improvements in supply chain processes are realized in a prototype decision support system so that a comparison is obtained before and after the application of technology. This study aims to map supply chain disturbances in the furniture industry today based on the obstacles, resistances, and causes detected as the basis for consideration of making a decision support system prototype. The scope of this study is to identify disruptions in supply chain business processes using the DMAIC Six-Sigma method, then apply technology to overcome them. By implementing a decision support system in the supply chain process, it is hoped that the manufacturing industry can minimize potential losses, evaluate weights, and determine ways or alternative solutions for risk disturbances.

Literature review

Six Sigma

Six Sigma is a method to improve an industry's productivity and efficiency. Six Sigma is expected to develop business process capacity, improve performance and reduce the possibility of errors. The Six Sigma approach used is Define, Measure, Analyze, Improve, and Control (DMAIC) (Prashar, 2020). The first stage starts by determining the problem, objectives, and processes. The second stage is measuring the problem. The third stage, analyze the effectiveness and efficiency of the process to achieve the goal. The fourth stage identifies ways to improve or develop a process. The fifth stage, assessing the implementation of the strategy in the previous stage (Abualsaud et al., 2019).

Application of Six Sigma in various fields

The Six Sigma approach has helped achieve faster model adoption in several areas.

1. In Healthcare. Scheduling of visits and timing of each task, structure of the improvement process following the six sigma methodology. Simulation of the health care process benefits both hospital and patient management. Benefit from shorter waiting times for medical examinations through the excellent hospital and patient management and affect resource management (Improta et al., 2020; Vaishnavi & Suresh, 2020).
2. In SMS's Sector. The use of six sigma has succeeded in producing risk mapping in the tubular system of Microbially Induced Corrosion (MIC). The risk is the potential for increased corrosion and chemicals. Therefore, six sigma helps define ways to control, maintain and monitor the repair process of the tubular system (Patyal et al., 2019; Chandra et al., 2021).
3. In Transportation. The application of six sigma in the transportation sector aims to identify areas of improvement in determining bus drivers according to the route and type of bus. In addition, it is necessary to determine the factors that increase the overall risk. Simple adjustments to public transport services can reduce traffic accidents which are a critical problem (Kuvvetli & Firuzan, 2019; Adhyapak et al., 2019).

4. In Banking. Six sigma implementation in banking meets stakeholders' needs through customer feedback and complaints about financial products/services. Some improvements to the banking process can be in the form of defining customer satisfaction improvement programs, improving service/product quality, and adopting control systems in operational activities (Sunder et al., 2019; Prince et al., 2020).

Failure Mode and Effect Analysis (FMEA)

FMEA is one of the quality improvement and control programs that can prevent failures in the process. There are three important indicators in implementing or using the FMEA method. Severity (S) identifies the impact of loss. Occurrence (O) calculates the frequency of the risk of error. Detection (D) to find failures before impact certain processes (Eze & Eneh, 2022). The rating scale is based on Table 1.

Table 1 shows the rating scale used to determine the seriousness rating value for potential supply chain process failures. The supply chain processes assessed were the date and time of loss, failure phenomena, cause analysis, repairing failure processes, and machine downtime. The results of the Severity (S), Occurrence (O), and Detection (D) assessments are used as the basis for measuring the Risk Priority Number (RPN) using the RPN = S × O × D equation. RPN provides information to determine the priority of potential failures in components.

Materials and methods

Data collection

The data collection procedure was carried out by distributing questionnaires containing questions related to supply chain risks. The supply chain risk that has been defined is then assessed from the sources regarding severity, occurrence, and detection. Recording or documentation is also done based on direct observation in the manufacturing industry. The data collected refer to supply chain disruptions in marketing, finance, and production flows. Data collection provides an overview of the research situation and conditions in the field (Subriadi & Najwa, 2020).

Research stages

The research stages are shown in Figure 1.

The first step is to formulate the problem of disturbances in the supply chain from 3 supply chain flows,

Table 1
Rating scale of severity, occurrence, detection (Salvi & Jindal, 2018)

Level	Severity		Occurrence		Detection	
	Effect	Criteria	Probability	Failure criteria	Convenience	Criteria
1	No effect	No influence	Never happen	No more than 10,000 hours	Almost certain	Easy to do/visible
2	Very minor effect	The system is still working perfectly	Almost never	Between 6001 to 10,000 hours	Very high	Very easy to detect
3	Minor effect	Decreased performance	Very rare	Between 3001 to 6000 hours	High	Easy to detect
4	Very low	Downtime up to 30 minutes	Rarely	Between 2001 to 3000 hours	Moderately high	Quite high to be detected
5	Low	Downtime 30 minutes to 1 hour	Low	Between 1001 to 2000 hours	Moderate	Moderate chance will be detected
6	Moderate	Downtime 1-3 hours	Intermediate	Between 401 to 1000 hours	Low	Small next failure cause detected
7	High	Downtime 4-7 hours	High enough	Between 101 to 400 hours	Very low	Very small detected
8	Very high	Downtime more than 8 hours	High occurs	Between 11 to 100 hours	Remote	Remote possibility of detecting
9	Hazardous with warning	The system is not operating	Very high	Between 2 to 10 hours	Very remote	Very little chance
10	Hazardous without warning	Causing an accident	Every time	Less than 1 hour	Absolute uncertainty	Impossible to detect

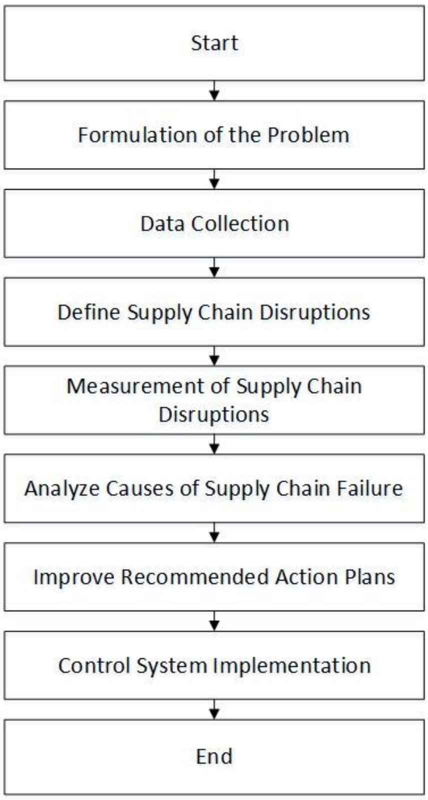

Fig. 1. Research stages (Ghadage et al., 2020)

namely marketing, production, and finance. The second step is to collect data using questionnaires and field observations. The third step is defining the supply chain's disruption and its impact. The fourth step is to measure supply chain disruptions using the Failure Mode and Effects Analysis (FMEA) approach. This stage measures the failure rate (Severity-S), the probability of occurrence (Occurance-O), and the failure detection rate (Detection-D) (Albertivan et al., 2019). The fifth step is to analyze the impact of disruption on time, quality, and cost based on a user questionnaire. The sixth step is to improve the current supply chain process by determining improvement priorities based on the highest RPN value from the FMEA. The last step is implementing a prototype decision support system as a proposed improvement. After realizing the system prototype, a comparative analysis of the RPN was carried out before and after the system implementation trial. This research's novelty is overcoming defects in business processes in the manufacturing industry by applying the latest technology. The application of this technology is in the form of making a decision support system to overcome disruptions in the supply chain flow of the marketing, accounting, and production sections.

Results

Define supply chain disruptions

This stage is the first step to determining the problem, research objectives, and scope of the process. The define stage has steps:

1. SIPOC (Supplier, Input, Process, Output, Customer). The method of identifying business elements used in process improvement activities. This SIPOC identification is usually made before the process improvement project begins. Figure 2 provides an overview (at a high level) to understand the critical elements of a business process. Figure 2 shows the SIPOC of improving each essential business process element. SIPOC can define process boundaries and identify outputs and gaps according to customer requirements. After that, it will be determined what is the Critical To Quality (CTQ) for the customer or what is considered problematic by the customer.

Fig. 2. SIPOC Diagram (Based on the author's conception of industrial business processes)

2. SIPOC Diagram (Based on the author's conception of industrial business processes).
3. Identify the type and impact of disruption (Based on the author's conception of industrial business processes).
4. Critical To Quality (CTQ). Breaking down consumer needs quite diverse into needs that can be quantified and easier to process. This stage is carried out for supply chain disturbances, which is the first step in identifying supply chain performance disturbances that you want to fix. Some disturbances can be experienced in the supply chain process, such as demand, supply, control, and environmental (Shekarian & Mellat Parast, 2021). The manufacturing industry needs to define the product disruption occurring during one year (Table 2). Table 2 shows the number of disruptions experienced by the manufacturing industry in the marketing, finance, and production divisions. Based on observational data, the total number of products produced is 2,381. Within 12 months, the total disruption/defect experienced from business processes was 374 units. The defects that often occur are wrong order data, damaged products, production not finished, and empty raw materials.

Measurement of disruptions

In this phase, the process capability value will be known by measuring the Defect Per Million Opportunity (DPMO) and Sigma Level values based on CTQ. In the measuring stage, data is collected regarding the type and number of existing defects. The data collected is regarding the number of pack defects and the type of pack defects. Defects Per Million Opportunity (DPMO) calculations and sigma-level achievements are also carried out at this stage. DPMO calculation using the formula:

$$\text{DPMO} = \frac{\text{Total Product Defect}}{\text{Production (Unit)} \times \text{CTQ}} \times 1\,000\,000 \quad (1)$$

The obtained DPMO is then converted into sigma-level achievements using a six sigma conversion table. DPMO and Sigma level values can be seen in (Table 3). Table 3 shows the number of products produced and the number of defective products obtained. Based on the results of the DPMO calculation using the previous formula, the total DPMO value is 26110 with a sigma value of 3.44.

Table 2
Identify the type and impact of disruption (Based on the author's conception of industrial business processes)

Month	Production (Unit)	Type of Defect				Total product defect
		Wrong Order Data (X1)	Damaged Product (X2)	Production Not Finish (X3)	Empty Raw Material (X4)	
January	343	12	8	8	9	37
February	468	10	7	5	8	30
March	397	8	8	7	7	30
April	341	7	6	6	10	29
May	239	7	8	11	8	34
June	297	8	9	8	8	33
July	301	13	8	8	7	36
August	282	10	6	7	7	30
September	224	11	7	6	8	32
October	199	8	6	6	5	25
November	207	8	9	8	6	31
December	283	7	8	5	7	27
Total	3581	109	90	85	90	374
Average	298	9.08	7.5	7.08	7.5	31.16

Table 3
DPMO and Sigma Level (Based on the author's conception of industrial business processes)

Month	Production (Unit)	Total Product Defect	CTQ	DPMO	Sigma
January	343	37	4	26967	2.12
February	468	30	4	16025	3.64
March	397	30	4	18891	3.59
April	341	29	4	21261	3.53
May	239	34	4	35564	3.31
June	297	33	4	27777	3.42
July	301	36	4	29900	3.39
August	282	30	4	26595	3.43
September	224	32	4	35714	3.31
October	199	25	4	31407	3.36
November	207	31	4	37439	3.28
December	283	27	4	23851	3.48
Total	3581	374	48	26110	3.44
Average	298	31.16	4	26110	3.44

Analyze causes of supply chain failure

The analysis stage is the third stage in the Six Sigma quality improvement method. In this phase, the causal relationship of various factors is analyzed to determine the dominant factors that need to be controlled. From the data collected in the Define and Measure phases, it is necessary to look for the production process and the factors that affect CTQ using a cause-and-effect diagram or an Ishikawa diagram.

Figure 3 shows the results of identifying the causes of problems with the quality of the resulting product. Identify the cause of the problem by using a cause-and-effect diagram. Cause data was obtained from direct observation of the production process and interviews. The following causes of disruption to business processes:

1. Humans. Operator performance is less than optimal because it does not use proper equipment standards. Several factors were the cause, including the wiping department was not careful in cleaning the production machine and the packaging department did not package the finished product according to standards. Then, the operator does not wear special gloves to manufacture the product – use gloves to minimize the factors that cause defects.
2. Materials. Factors that cause defects, namely the product's color, do not match due to an error in selecting raw materials at the beginning before production. The second factor is that the product's condition is dusty and rough because the function of wiping and painting is incorrect. Furthermore, the liquid paint on the product coagulates, resulting in defects at several points of the product because it is not cleaned properly before the painting process is carried out.
3. Environments. The factor that causes defects in the room temperature is too hot, making the product spoil faster. Then, the difference in room temperature in the painting process and drying too quickly cause damage to the product. At the time of product production, the electricity in the factory often fluctuates, which causes the machine to break down quickly.
4. Machines. Factors that cause defects are dust on the engine and improper timing during painting. The painting machine should spray when the sensor on the machine detects the product to be sprayed. However, the sensors on the machine often cannot detect the product to be sprayed.

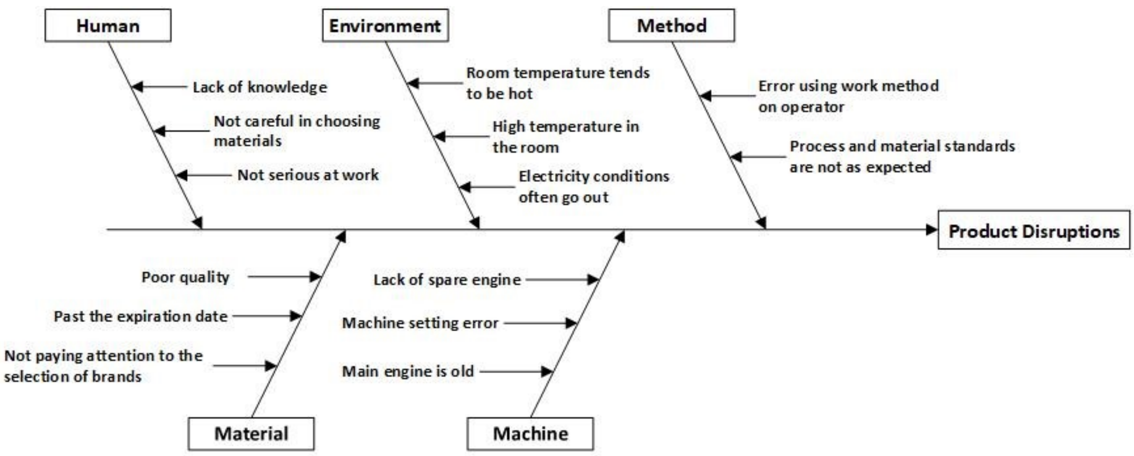

Fig. 3. Cause and Effect Diagram (Based on the author's conception of industrial business processes)

5. Methods. One factor that causes defects is the inconsistent placement of workers. The number of operators is changing, so errors appear during production. Then, the standard of raw materials and the product production process do not match the established standard. For example, the product must go through a drying process for 60 minutes. However, due to workers' lack of understanding, drying was only for 30 minutes.

Improve recommended action plans

The Failure Mode and Effect Analysis (FMEA) measure of supply chain performance disturbances (Table 4). This process is carried out by identifying and weighting risks as a basis for considering the current failure evaluation.

Table 4 shows the results of the validation of the disruption and its impact on the manufacturing industry on the current supply chain. The use of FMEA produces a Risk Priority Number (RPN) derived from the multiplication of severity, occurrence, and detection. The repair phase is carried out by following the results of the calculation of the highest RPN value obtained from the Failure Modes, and Effects Analyze (FMEA) (Gul et al., 2020). The highest RPN value indicates that failures need to be prioritized for improvement. The proposed and implemented corrective actions are contained in the action plans.

Control system implementation

This stage is the last in applying six sigma using the DMAIC approach. This phase is to continuously control the process to improve process capability towards Six Sigma. New practices emerge in industrial operations that are driving the adoption of information technology (Chakir et al., 2021). A Decision Support System (DSS) can help the industry improve supply chain processes (Nurprihatin et al., 2021). The prototype system is shown in Figure 4.

In this stage, all the improvements made are realized in a system prototype. The proposed revision by implementing the system is based on the results of interviews and questionnaires distributed to manufacturing industry employees. Figure 4 shows a prototype system for supply chain marketing flows. Employees have tested this system in the manufacturing industry to create product orders. The comparison of RPN before and after the implementation of the system is

Table 4
FMEA Stages in the Manufacturing Industry Supply Chain
(Based on the author's conception of industrial business processes)

Type of Deffect	Impact	Bobot			RPN-Before	Action Plans	Priority
		S	O	D			
Wrong Order Data (X1)	Wrong product ordered	9	8	6	432	Validate the completeness of the required order letter	1
	Late payment of order bill					Incomplete customer data validation using the system	
	There is no limit to the information obtained					Separate access rights and responsibilities of system users	
Damaged Product (X2)	Production price increase	7	6	9	378	Production machine repair	2
	Reduced profit					Market needs survey	
	Product price goes up					Improvement of raw material selection	
Production Not Finish (X3)	Wrong decision, unclear asset information	6	5	7	210	Digital document collection, annual reporting	3
	Production does not match the queue and does not finish on time					Validation of the completeness of the production letter	
	The inconsistent flow of funds, no documentation					Calculation of financial statements using the system	
Empty Raw Material (X4)	Production cannot be done	5	4	5	100	Consistent recording of raw materials for incoming goods	4
	The product is not optimal					Ordering fewer raw materials can be made faster	
	Incorrect inventory report					Stock data updates every day	

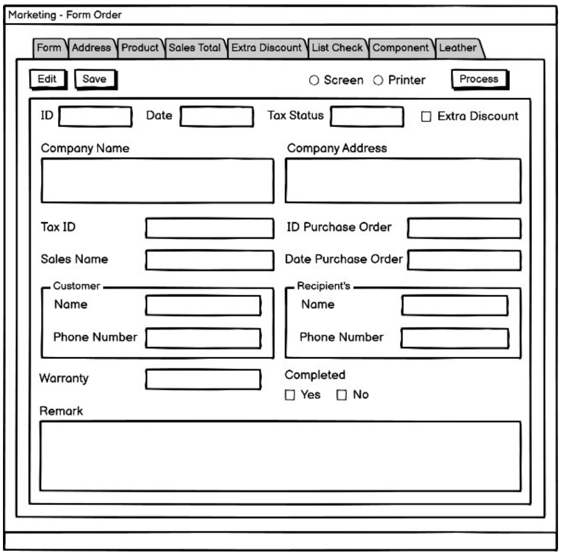

Fig. 4. System Prototype for Marketing (Based on the author's conception of industrial business processes)

shown in Figure 5.

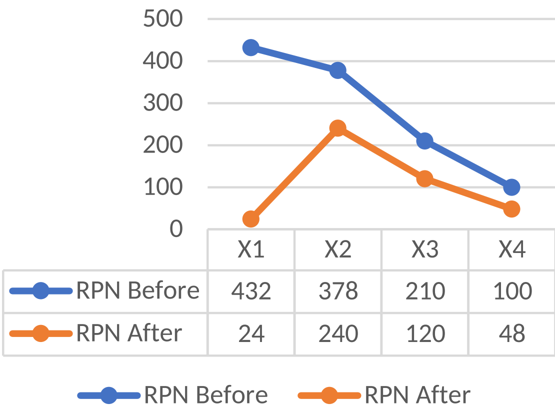

Fig. 5. RPN comparison chart before and after system prototype implementation (Based on the author's conception of industrial business processes)

Figure 5 shows the results of the comparison of the Risk Priority Number (RPN) values before and after implementing the decision support system. After implementing the system prototype, there is a reduction in risk, which indicates that the disruption has been reduced.

Discussion

The manufacturing industry experienced several disruptions to supply chain flows. These disturbances appeared in the marketing, finance, and production departments. As a result of the troubles that arise, it will impact the operations of the manufacturing industry. The perceived impacts include product ordering errors, wrong decisions, not optimal product results, and many more. After mapping the current supply chain disturbances, the S-O-D (Severity-Occurrence-Detection) value is measured. It is possible to weigh potential risks that need to be prioritized by measuring the S-O-D value. Risk prioritization uses the Failure Mode and Effect Analysis (FMEA) approach. The result of the FMEA is the Risk Priority Number (RPN) value. The RPN value is used as the basis for prioritizing potential disturbances [27] (Vaishnavi & Suresh, 2020). The greater the value of the RPN, the faster it is in risk handling. Making a decision support system prototype is done by prioritizing activities with the highest RPN to be implemented first. The results of identifying disturbances in the manufacturing industry are analyzed in more detail, whether affect time, quality, and cost. The identified risks are then analyzed with a simulation model to reduce supply chain problems. Supply chain management is one of the strategies to improve the performance of the system implementation later. After successfully implementing the decision support system, it is expected to reduce costs, increase efficiency, and improve the delivery of the final product or service on time to customers. The prototype created is used to address the supply chain flow of marketing, finance, and production. Based on the priority level defined from the RPN value, the system prioritizes the order data section first because it is at level 1. Employees have tested this system in the manufacturing industry, so it is expected to minimize disruptions in the supply chain process.

Conclusions

The dynamic development of the business world will affect the complexity of the supply chain in each industrial sector. One of the causes of supply chain instability is the occurrence of disturbances. Some of the complexities of today's supply chain processes are caused by a lack of logistics infrastructure, material and component quality issues, and much more. Therefore, a mapping of the current supply chain disruptions is needed to reduce the negative impact on the performance of the manufacturing industry. Mapping supply chain disturbances using the help of the Six Sigma method, which consists of 5 stages. Disruption mapping starts from identifying supply chain performance disruptions in the marketing, finance, and production processes. There are nine types of supply chain disturbances and the impact of these disturbances, in the form of order wrong order data, damaged products, production not finish, and empty raw materials. Furthermore, the measurement of supply chain disturbances is carried out using the Failure Mode and Effect Analysis (FMEA) approach, which produces a Risk Priority Number (RPN) value. The greater the value of the RPN, the faster it is in risk handling. Evaluation of supply chain risk whether the disruption experienced affects the manufacturing industry's time, quality, and cost. The results of the evaluation are used to define corrective actions taken. Risks that have a high assessment and cause supply chain failures need to be prioritized for improvement. Based on the priority level defined from the RPN value, the system prioritizes the order data section first because it is at level 1. Improvements to the supply chain process are translated into a decision support system prototype so that can see a comparison before and after the application of technology. After implementation, a survey was conducted among users to get the RPN value. The survey results prove a decrease in the value of the RPN, demonstrating that the application of the system can reduce the potential loss effect of the previous supply chain process. This research implies that supply chain management has a more significant role in improving company performance, so it is necessary to improve the process. Supply chain improvements are realized by applying technology in the form of a decision support system based on the current condition of the company's business processes.

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