

Defining Action Plans to Reduce Defects in a Paper Production Line Using Statistical Process Control and Fuzzy Analytical Hierarchy Procedure

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Abstract

Defect prevention in products is essential to improve production efficiency and improve product quality in accordance with consumer expectations. Action plants to prevent defects in a paper factory were tried to be found in this research. The action plan was obtained using Statistical Process Control to control production to comply with specific limits, and Fuzzy Analytical Hierarchy Procedure used to find the priority of the problem. The data collected showed that the primary defects were in the form of wrapping alignment and folding sheets. Analysis showed that wrapper properties and the length of time the wrapper roll on the floor caused the problems. To overcome the causes of the problems, three action plans need to be taken: training, creating SOPs, and creating maintenance checklists.

1. Introduction

Quality is not a single attribute but a complex concept that combines customer expectations and ensures product perfection. It's about giving customers what they want while ensuring there are no problems or imperfections that might hinder their satisfaction. This combination of meeting demands and ensuring excellence forms the core of a comprehensive understanding of quality in various fields [1-4]. Quality control is a process used to ensure products or services meet established standards. Quality control is used as a system to maintain the desired level of quality in a product or service. Quality control involves a structured approach to managing factors that influence product quality, which depend on materials, equipment, machines, type of labour, and working conditions [5-7].

One of the approaches in quality control is the Statistical Process Control (SPC), a method that helps evaluate the alignment of output at each production stage with product design standards. The SPC plays an important role in ensuring every step of the production process is aligned with predetermined parameters to produce optimal quality. More than just detecting problems, this approach emphasizes preventing problems in the first place. The main goal is to achieve consistent and optimal quality throughout the production process [6, 8-10]. The SPC can proactively identify changes or variations that may occur in the production process before they develop into significant problems. This allows companies to make necessary repairs or adjustments quickly and promptly, ensuring that high-quality standards are maintained in every item produced [11-13].

The statistical techniques presented by SPC offer the ability to optimize the amount of information required for decision-making, through a deep understanding of the fundamental aspects of a business. It also provides

important insights for process improvement, as well as facilitating communication of the values and outcomes of existing processes, all reinforced by the active and clear involvement of various stakeholders. The SPC creates opportunities for real-time analysis that allows the establishment of controllable baselines. This includes a continuous learning process, establishing stable parameters, and continuous improvement in the dynamic capabilities of a process [9,14].

The application of SPC is not only about identifying problems that arise in the production process but also about identifying potential sources of problems in the future. The results of this evaluation are the starting point for developing a systematic action plan to overcome the identified problems. To ensure that the selected action plan is not only effective but also strategically urgent, this research applies the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) method. This method allows the company to evaluate each proposed action plan from a variety of different points of view, involving assessments and considerations from various experts within the company [15-16]. Leveraging collective expertise and experience, Fuzzy AHP assists in the priority of action plans that are most important and strategic. This careful evaluation process allows the company to allocate resources wisely, focusing on resolving problems that significantly impact the production process, ensuring smoothness and quality in the final products manufactured [17-19].

Through this approach, Fuzzy AHP provides the ability to describe and quantify the level of uncertainty and ambiguity associated with structured decision-making [20]. For example, in assessing the preference or value of each pair of attributes, determining the degree of membership on a fuzzy scale can describe how much a pair of attributes fall into a particular category, even when the boundaries between categories are not clearly defined. Fuzzy-AHP's ability to adapt to this uncertainty is an integral part of decision analysis based on fuzzy logic. In this way, Fuzzy AHP not only results in more structured decision-making but also enables understanding and measuring uncertainty related to preferences or judgments made in complex decision contexts [15,17-18]. Therefore, the improvement steps taken are prioritized based on their level of importance [21-26].

In the domain of paper converting technology, the assurance of efficient production and the attainment of specialized product characteristics necessitate stringent process control due to the inherently continuous nature of operations [27-29]. Contemporary paper manufacturing systems are fundamentally dependent on rigorous quality control protocols to sustain operational efficacy. In order to realize this objective, a pre-emptive methodology that encompasses the examination of process irregularities and the execution of automated remedial measures is imperative for the eradication of defects. This approach, which integrating statistical process control with executable strategies, is vital for the attenuation of variances and the enhancement of paper production quality, as underscored in research that concentrates on defect mitigation techniques within the paper manufacturing sector.

The synergistic integrating of Statistical Process Control (SPC) with the Fuzzy AHP establishes a comprehensive framework that significantly enhances decision-making processes in the realm of defect management in paper converting. By utilizing Fuzzy AHP, manufacturing company can adeptly integrate expert evaluations to formulate weighted priorities for various defect categories, thereby ensuring that critical concerns are addressed through informed deliberations [29]. Moreover, the complementary utilization of SPC permits an exhaustive analysis of defects, thereby enabling the identification of underlying causes and the formulation of effective remedial strategies, which in turn enhances the overall precision in defect resolution [30]. This integrated methodology ultimately fosters more accurate prioritization and effective problem-solving [31-33] within paper manufacturing companies.

A method to obtain an action plan to improve quality and reduce defects using SPC and Fuzzy AHP is proposed in this study. Defects in a paper factory production line are attempted to be overcome through the best action plan that can be implemented according to the current conditions of the company. The action plan is determined using SPC to control production to comply with specific limits, and the Fuzzy AHP is used to find the priority of the problem and action plan.

2. Method

Defects in one product can occur in various forms. However, not all defects need immediate correction. Immediate correction needs to be done for defects that exceed the permitted limits that can be checked using SPC control chart. Action plans are necessary to reduce defect work by reducing root cause of the defect. For the action plan to be effective, it is necessary to sort root causes based on their influence on defects. The Fuzzy AHP method, which has proven to be reliable in determining the priority of several options, can be used for this purpose.

Defining the action plan to reduce defects in this study was started by collecting data on the types and number of defects. This data was then analyzed using SPC to identify defects beyond the acceptable limit. Based on the SPC result, possible damage causes were identified using a cause-and-effect diagram. The causes of the defects were then sorted from the strongest to the weakest using Fuzzy AHP. These results were then used to determine the action plan to reduce defects.

2.1 Data Collection

The case study data collected in PT RST, at the paper cutting department. Various quality defects encountered during the paper cutting, wrapping and packing processes were collected at Cut Size#2 (CS#2) in the production line. The data presented in Table 1, was collected from July to December 2022, which covers a significant period needed to assess the problem comprehensively.

Table 1 Product defects at CS#2 production line from July-December 2022

Machine defects types	July (Reams)	August (Reams)	September (Reams)	October (Reams)	November (Reams)	December (Reams)	Total (Reams)
Paper shade		5	1				6
Roll quality			1				1
Wrinkle	40					25	65
Bad cutting	1		10				11
Bad slitting	25		5		27		67
Length deviation							0
Length variation			10			150	160
Width deviation						20	20
Width variation				10		10	20
Un-square							0
Poor jog	2	20	58	30	11	5	137
Hairy corner			25			10	35
Folding sheet	52		36	20	60	52	265
Marking Sheet					5		5
Torn sheet	11				1	6	19
Sheet stacking out	1	5	31	1			38
Dirty sheet	10			30			40
Tape not complete							0
Wrapper brand	30						30
Wrapper alignment		95	33	32	50	23	283
Wrapper glue quality	50		16	5	23	5	116
Glue on sheet							0
Ream tightness							0
Ink jet code	5					10	15
Torn wrapper							0
Wrapper marking							0
Bad printing code	55	60			15	30	175
Wrapper bad folding			105		10	5	130
Box brand							0
Lid and bottom quality	120					7	127
Glue quality	5	10			43		96
Number of ream per box			2				2
Ink jet code on box			5	15	10	1	36
Bad folding box		41		1		10	52
Torn box		10		5		5	20
Strapped							0
Total reject per month	407	246	338	149	255	374	1971
Production per month	2,358,415	1,811,470	2,317,480	1,565,558	2,270,875	2,032,730	14,228,133
Percentage of defect	0.017%	0.014%	0.015%	0.010%	0.011%	0.018%	

2.2 Statistical Process Control

Statistical Process control (SPC) is a statistical based method to improve and maintain the quality of products. The SPC can monitor a process to identify special causes of variation in quality and produce a signal whether a corrective action is needed. In this study p-chart was used to monitor the number of defective products in a production batch. Product defects are categorized into two types, namely permitted and unpermitted defects. Permitted defects are those between the Lower Control Limit (LCL) and Upper Control Limit (UCL) on the p-chart. The LCL and UCL are determined from Eq. (1) and Eq. (2). [11, 34]:

$$UCL = CL + 3 SD \tag{1}$$

$$LCL = CL - 3 SD \tag{2}$$

Centre Line (CL) and Standard Deviation (SD) are the average fraction non-conforming and estimate standard deviation respectively. The np is number of defectives per sub group; n subgroup or sample size.

$$CL = \frac{\sum np}{\sum n} \tag{3}$$

$$SD = \sqrt{\frac{\sum (np - CL)^2}{\sum n - 1}} \tag{4}$$

2.3 Fuzzy AHP Approach for Decision Making

AHP is a multi-criteria decision method that breaks down complex problems into simpler hierarchical structures using pair-wise comparison to obtain priorities order in the form of and weights factors from several alternatives. Subjectivity in pair-wise comparisons leads to scores that are affected by the inherent vagueness and imprecision of human perception. To eliminate the imprecise of human judgment in the score, scores in the form of fuzzy numbers are introduced instead of the precise or crisp ones used in the original AHP. The AHP with a fuzzy number score is known as Fuzzy AHP.

In this study, AHP with fuzzy trapezoid numbers, as explained by Tasri and Susilawati (2019) [16, 19], was used to obtain weigh of several root causes of product defects and action plans to overcome these defects. The steps of Fuzzy AHP are as the following:

- Once the root causes or action plan are found, the group of k experts compares the root cause in a pair-wise manner regarding their impact on causing the defect. For simplification, the root cause or action plan is called as alternative in this section. The pair-wise comparison gives a score to an alternative in the form of the script number between of 1-9. A rating of 1 indicates equal importance between two criteria, while a rating of 3 signifies that one criterion has a slight advantage over the other. Scores 5, 7, and 9 indicate enormously more important, strongly more important, and absolutely more important, respectively. Each expert produces one comparison matrix so that k comparison matrices are obtained. The matrix is shown in Eq. (5).

$$C_k = \begin{bmatrix} c_{11k} & c_{12k} & c_{13k} & \dots & c_{1nk} \\ c_{21k} & c_{22k} & c_{23k} & \dots & c_{2nk} \\ \cdot & & & & \\ \cdot & & & & \\ c_{n1k} & c_{n2k} & c_{n3k} & \dots & c_{nnk} \end{bmatrix} \tag{5}$$

Subscripts a and b in c_{abk} represent the importance score of the alternative a^{th} against b^{th} . The k represented the opinion of the expert k^{th} . In this pair, comparison c_{ba} is equal to $1/c_{ab}$.

- Each member of the comparison matrix in Eq. (5) is in the form of a script number. The element of the comparison matrix was then transformed into a trapezoid fuzzy number following the rule in Table 2 result k fuzzy comparison matrix in Eq. (6):

$$c_k = \begin{bmatrix} \tilde{c}_{11k} & \tilde{c}_{12k} & \tilde{c}_{13k} & \tilde{c}_{1nk} \\ \tilde{c}_{21k} & \tilde{c}_{22k} & \tilde{c}_{23k} & \tilde{c}_{2nk} \\ \cdot & & & \\ \cdot & & & \\ \tilde{c}_{n1k} & \tilde{c}_{n2k} & \tilde{c}_{n3k} & \tilde{c}_{nnk} \end{bmatrix} \tag{6}$$

where \tilde{c}_{abk} represent the importance of the alternative a^{th} against b^{th} in the form of fuzzy number, awarded by expert k^{th} .

Table 2 Fuzzy number of script score

Script score	STFN	Linguistic Variable
1	(0, 0,5, 1,5, 2)	Equally important
3	(2, 2,5, 3,5, 4)	Weakly important
5	(4, 4,5, 5,5, 6)	Essentially important
7	(6, 6,5, 7,5, 8)	Very strongly important
9	(8, 8,5, 9,5, 10)	Absolutely important
$x = 2, 4, 6, 8$	$(x - 1, x - 0,5, x + 0,5, x + 1)$	Value between two levels

- The k collection of comparison matrices is then aggregated to be a single matrix representing the opinions of all experts. The aggregation is done by summing members of the expert opinion’s matrices with the same line and column multiplied by the corresponding weight factor, as shown in Eq. (7).

$$\tilde{C}_{rs} = \sum_{i=1}^n w_i \tilde{C}_{rsi} \tag{7}$$

- The weight factor w_i is calculated using Eq. (8).

$$w_i = \frac{S(C_i)}{\sum_{t=1}^n S(C_t)} S(C_t) = \sum_{t=1}^n d(\tilde{C}_t, \tilde{C}_i) \tag{8}$$

with $d(\tilde{C}_t, \tilde{C}_i)$ is distance of fuzzy number:

$$d(\tilde{C}_t, \tilde{C}_i) = d(\tilde{C}_t, \tilde{C}_0) - d(\tilde{C}_i, \tilde{C}_0) \tag{9}$$

$d(\tilde{C}_t, \tilde{C}_0)$ is the distance of fuzzy number \tilde{C}_t and a singleton \tilde{C}_0 which determined by Eq. (10)

$$d(\tilde{C}_2, \tilde{C}_0) = \left[C_{22}^2 + C_{23}^2 + \frac{(C_{22} - C_{21})^2}{3} + \frac{(C_{24} - C_3)^2}{3} - C_{22}(C_{22} - C_{21}) + C_{23}(C_{24} - C_{23}) \right]^{1/2} \tag{10}$$

where C_{21}, C_{22}, C_{23} and C_{24} is member of fuzzy number \tilde{C}_2 .

- Fuzzy number members of aggregated matrix is then defuzzified to be script number using Eq. (11)

$$C_{ij} = \frac{a_1 + 2a_2 + 2a_3 + a_4}{6} \tag{11}$$

a_1, a_2, a_3 and a_4 are the components of trapezoid fuzzy number as shown in Table 1.

- The weight of the t^{th} alternative is determined by averaging elements in row t^{th} of the aggregated matrix in step (d), which is normalized by the sum of the average of every row of the aggregate matrix. The averaging is done by using geometric mean rather than simple arithmetic mean using Eq. (12)

$$w_t = \frac{r_t}{\sum_{t=1}^n r_t} \tag{12}$$

$$r_t = \left(\prod_{i=1}^n c_{ti} \right)^{1/n} \tag{13}$$

w_t is the weight of t^{th} alternative, r_t is geometric mean of row t^{th} of defuzzified aggregated matrix, c_{ti} element of row t^{th} of the defuzzified aggregated matrices.

- The Consistency of the comparison matrix (Eq. (5)) is determined using the consistency ratio suggested by Saaty [35]. The consistency ration is defined as:

$$CR = \frac{CI}{RI} \tag{14}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{15}$$

λ_{max} is the largest eigen-value of aggregate matrix, and n is the size of the matrix. RI is a random index that depends on the aggregate matrix's size. RI for several n can determine from Table 3.

Table 3 Random Index (RI) Saaty [35]

n	1	2	3	4	5	6	7	8	9	10
RI	0.0	0.0	0.58	1.12	1.24	1.32	1.14	1.45	1.49	1.51

3. Result and Discussion

Defect data (Table 1) was collected between July to December 2022. The defect type is shown in the first column, and the number of defects is shown in the next column. The total defect and sample size, which was equal to monthly production, were shown at the bottom of the table. The data was then presented as a Pareto chart in Fig. 1. The chart revealed the wrapping alignment occurs most frequently, with a total of 283 from July to December, followed by folding sheet defects with 265 occurrences.

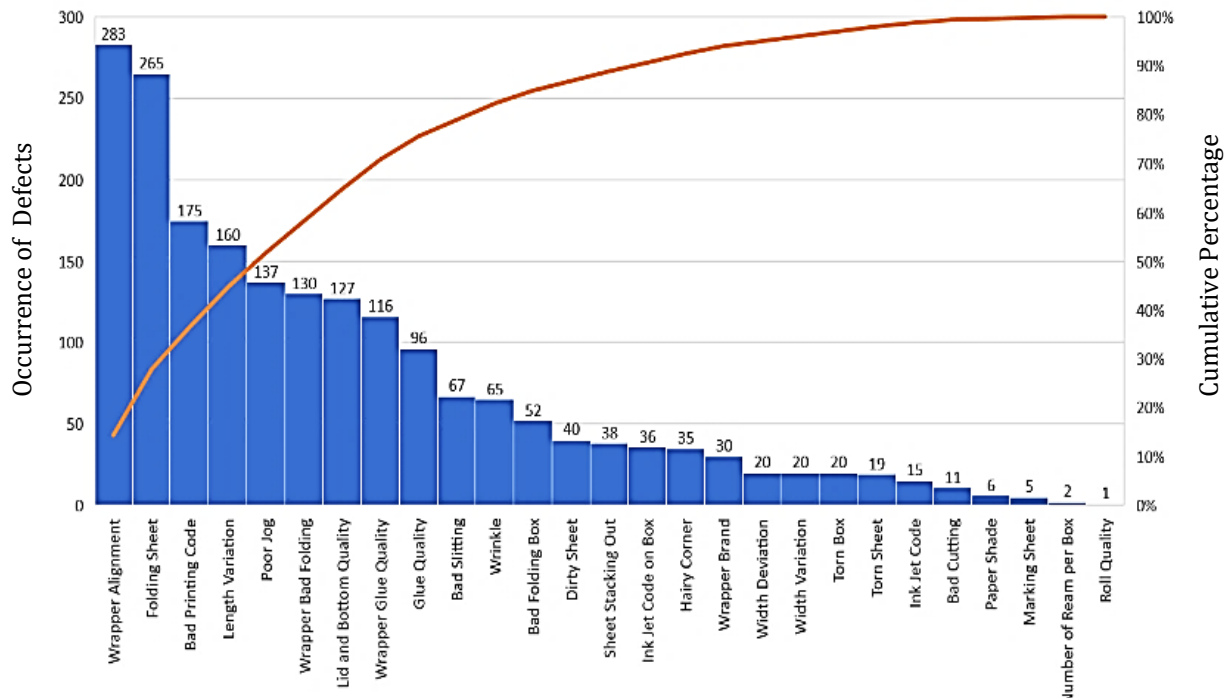


Fig. 1 Pareto diagram of defects on CS#2

Wrapper alignment, folding sheet, bad printing code, and length variation were the most frequent defects. The wrapper alignment issues signify misalignments during the wrapping process, potentially leading to inefficiencies in packaging and product quality. The Folding Sheet problem indicates inconsistencies or flaws in the folding stage, affecting the final product's presentation and functionality. Bad Printing Code highlights errors or faults in the printed information, impacting the product's branding and information communication. Length Variation denotes discrepancies or irregularities in product sizing, possibly leading to customer dissatisfaction and usability concerns. This issue needs immediate attention and targeted corrective measures. Addressing these issues effectively is crucial not only to enhance product quality but also to optimize production output and maintain customer satisfaction levels at CS#2.

A control chart, in the form of a p-chart, was used to determine whether the defects within the permissible limits. A sample p-chart for production during December is shown in Fig. 2. The chart has an Upper Control Limit (UCL) of 92.95 and a Lower Control Limit (LCL) of -68.82. However, defect or defect values cannot realistically dip below zero in practical application. Thus, the derived lower limit value of -68.82 has been adjusted to zero for greater practicality and accurate representation of the lower threshold. Throughout the majority days of the month, the reject or defect data consistently fell within the established boundaries, reflecting a stable manufacturing process that adhered to the predefined quality standards. However, the culmination of the month, specifically on December 31st, presented an unforeseen anomaly. This condition marked a significant deviation from the norm, showcasing an abrupt upsurge in rejects that surpassed the upper limit, indicating a notable disruption in the smooth production flow. This unexpected occurrence on the final day of the month drew attention to a sudden and irregular increase in defects, warranting a closer inspection to determine the underlying cause behind this deviation from the usual trend.

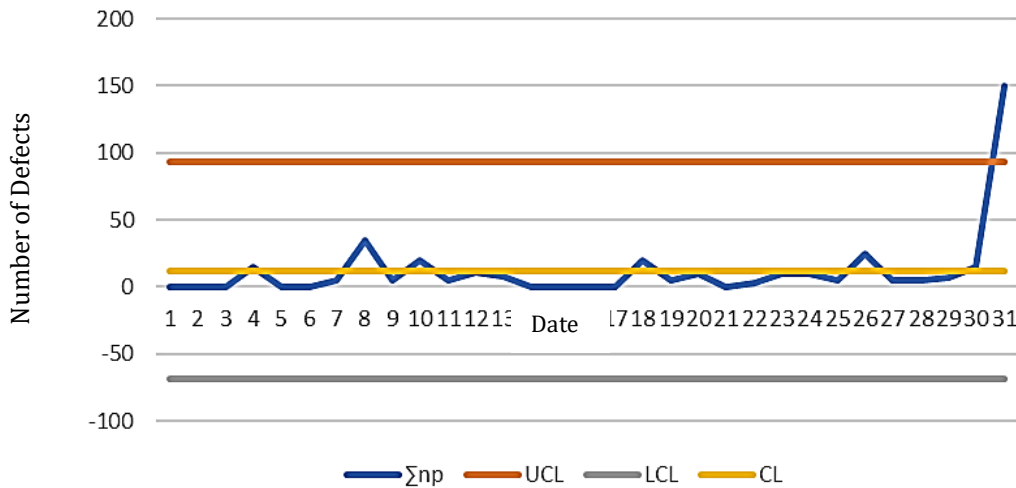


Fig. 2 The control chart of defects CS#2 at December 2022

Wrapper alignment and folding sheets were the most frequent and the leading cause of defects outside the safe range on the p-chart. These two types of defects need immediate handling. The root cause of these defects is determined using a fishbone diagram. It is shown in Table 3. To determine an action plan for reducing defects, the root caused must be sorted based on their effect on the defect. The sorting was done using Fuzzy AHP. Several experts were invited to give opinions on how much each root cause affects the defect in the form of pair-wise comparison. The pair-wise comparison scores for wrapper alignment and folding sheet problems are shown in Table 4 and Table 5. The original scores were in the form of script value. The score was then transferred to a standard trapezoidal fuzzy number (STFN) using the rule in Table 2. Following the Fuzzy AHP procedure in Section 2.2, the weight of the root caused was determined as shown in Fig. 3 and Fig. 4.

Fig. 3 revealed that the wrapping alignment defect was most likely caused by wrapper properties, which have a weight of 0.228, followed by the length of time wrapper roll on the floor and operator-related issues, with weights of 0.187 and 0.151, respectively. Other potential caused such as the worn plate transfer, slippery vacuum belt, and broken bearing have intermediate likelihoods. These factors may still play a role, but they were less likely to be the primary cause than the wrapper properties. In Fig. 4 shows that the folding sheet problem was mainly caused by wrapper properties, the length of time wrapper roll on the floor and the lag of operator knowledge with weights 0.368, 0.372 and 0.151, respectively. This indicated that the quality of the wrapper material or its storage conditions may play a crucial role in terms of defect problems.

Table 3 The wrapper alignment and folding sheet problems

The Wrapper Alignment Problem	Code	Folding Sheet Problem	Code
Operator didn't know how to adjust properly	2P-A	Operator didn't know how to adjust properly	1P-A
Operator did not really care with the problem	2P-B	Operator did not really care with the problem	1P-B
Wrapper properties	2P-C	Wrapper properties	1P-C
The wrapper roll has been on the floor for a long time	2P-D	The wrapper roll had been on the floor for a long time	1P-D
Plate transfer was worn	2P-E	Chamber shoe was worn out	1P-E
Vacuum belt was slippery	2P-F	Transfer belt was worn	1P-F
Bearing for vacuum belt was broken	2P-G		

Table 4 Score of pair-wise comparison of the sub-matrix for wrapping alignment issue

Expert	1PA-A		1PA-B		1PA-C		1PA-D		1PA-E		1PA-F		1PA-F		
	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	
1P-A	E1	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/7	(1/8, 2/15, 2/13, 1/6)	1/7	(1/8, 2/15, 2/13, 1/6)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)
	E2	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/6	(1/7, 2/13, 2/11, 0.2)	1/6	(1/7, 2/13, 2/11, 0.2)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)
	E3	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/8	(1/9, 2/17, 2/15, 1/7)	1/8	(1/9, 2/17, 2/15, 1/7)	8	(7, 7.5, 8.5, 9)	9	(8, 8.5, 9.5, 10)	9	(8, 8.5, 9.5, 10)
	Aggregate	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)			(0.13, 0.14, 0.16, 0.17)		(0.13, 0.14, 0.16, 0.17)		(6, 6.5, 7.5, 8)		(6.5, 7, 8, 8.5)		(6.5, 7, 8, 8.5)
1P-B	E1			1	(1, 1, 1, 1)	1/7	(1/8, 2/15, 2/13, 1/6)	1/7	(1/8, 2/15, 2/13, 1/6)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)
	E2			1	(1, 1, 1, 1)	1/6	(1/7, 2/13, 2/11, 0.2)	1/6	(1/7, 2/13, 2/11, 0.2)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)
	E3			1	(1, 1, 1, 1)	1/8	(1/9, 2/17, 2/15, 1/7)	1/8	(1/9, 2/17, 2/15, 1/7)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)
	Aggregate			(1, 1, 1, 1)			(0.13, 0.14, 0.16, 0.17)		(0.13, 0.14, 0.16, 0.17)		(6, 6.5, 7.5, 8)		(6, 6.5, 7.5, 8)		(6, 6.5, 7.5, 8)
1P-C	E1				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)	
	E2				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	
	E3				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)	
	Aggregate					(1, 1, 1, 1)		(0, 0.5, 1.5, 2)		(6, 6.5, 7.5, 8)		(6, 6.5, 7.5, 8)		(6, 6.5, 7.5, 8)	
1P-D	E1					(1, 1, 1, 1)	1	(1, 1, 1, 1)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)	7	(5, 5.5, 6.5, 7)	
	E2					(1, 1, 1, 1)	1	(1, 1, 1, 1)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	6	(5, 5.5, 6.5, 7)	
	E3					(1, 1, 1, 1)	1	(1, 1, 1, 1)	9	(8, 8.5, 9.5, 10)	8	(7, 7.5, 8.5, 9)	8	(7, 7.5, 8.5, 9)	
	Aggregate							(1, 1, 1, 1)		(6.5, 7, 8, 8.5)		(6, 6.5, 7.5, 8)		(6, 6.5, 7.5, 8)	
1P-E	E1								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	
	E2								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	
	E3								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	
	Aggregate									(1, 1, 1, 1)		(0, 0.5, 1.5, 2)		(0, 0.5, 1.5, 2)	
1P-F	E1										1	(1, 1, 1, 1)	1	(1, 1, 1, 1)	
	E2										1	(1, 1, 1, 1)	1	(1, 1, 1, 1)	
	E3										1	(1, 1, 1, 1)	1	(1, 1, 1, 1)	
	Aggregate											(1, 1, 1, 1)		(1, 1, 1, 1)	

(Source: Authors own calculations)

Table 5 Score of pair-wise comparison of the sub-matrix for bad folding issue

Expert	2PA-A		2PA-B		2PA-C		2PA-D		2PA-E		2PA-F		2PA-G		
	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	Scale	STFN	
2P-A	E1	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/3	(1/4, 2/7, 0.4, 0.5)	1/3	(1/4, 2/7, 0.4, 0.5)	3	(2, 2.5, 3.5, 4)	3	(2, 2.5, 3.5, 4)	3	(2, 2.5, 3.5, 4)
	E2	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/2	(1/3, 0.4, 2/3, 1)	1/2	(1/3, 0.4, 2/3, 1)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)
	E3	1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1/2	(1/3, 0.4, 2/3, 1)	1/2	(1/3, 0.4, 2/3, 1)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)
	Aggregate	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)			(0.29, 0.34, 0.53, 0.75)		(0.29, 0.34, 0.53, 0.75)		(1.5, 2, 3, 3.5)		(1.5, 2, 3, 3.5)		(1.5, 2, 3, 3.5)
2P-B	E1			1	(1, 1, 1, 1)	1/4	(0.2, 2/9, 2/7, 1/3)	1/4	(0.2, 2/9, 2/7, 1/3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)
	E2			1	(1, 1, 1, 1)	1/3	(1/4, 2/7, 0.4, 0.5)	1/3	(1/4, 2/7, 0.4, 0.5)	3	(2, 2.5, 3.5, 4)	3	(2, 2.5, 3.5, 4)	3	(2, 2.5, 3.5, 4)
	E3			1	(1, 1, 1, 1)	1/2	(1/3, 0.4, 2/3, 1)	1/2	(1/3, 0.4, 2/3, 1)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)
	Aggregate			(1, 1, 1, 1)			(0.27, 0.31, 0.48, 0.66)		(0.27, 0.31, 0.48, 0.66)		(1.5, 2, 3, 3.5)		(1.5, 2, 3, 3.5)		(1.5, 2, 3, 3.5)
2P-C	E1				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	
	E2				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	
	E3				1	(1, 1, 1, 1)		(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	2	(1, 1.5, 2.5, 3)	
	Aggregate					(1, 1, 1, 1)		(0, 0.5, 1.5, 2)		(1, 1.5, 2.5, 3)		(1, 1.5, 2.5, 3)		(1, 1.5, 2.5, 3)	
2P-D	E1						1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	E2						1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	E3						1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	Aggregate							(1, 1, 1, 1)		(0, 0.5, 1.5, 2)		(0, 0.5, 1.5, 2)		(1, 1.5, 2.5, 3)	
2P-E	E1								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	E2								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	E3								1	(1, 1, 1, 1)	1	(0, 0.5, 1.5, 2)	2	(1, 1.5, 2.5, 3)	
	Aggregate									(1, 1, 1, 1)		(0, 0.5, 1.5, 2)		(1, 1.5, 2.5, 3)	
2P-F	E1										1	(1, 1, 1, 1)	2	(1, 1.5, 2.5, 3)	
	E2										1	(1, 1, 1, 1)	2	(1, 1.5, 2.5, 3)	
	E3										1	(1, 1, 1, 1)	2	(1, 1.5, 2.5, 3)	
	Aggregate											(1, 1, 1, 1)		(1, 1.5, 2.5, 3)	
2P-G	E1												1	(1, 1, 1, 1)	
	E2												1	(1, 1, 1, 1)	
	E3												1	(1, 1, 1, 1)	
	Aggregate													(1, 1, 1, 1)	

(Source: Authors own calculations)

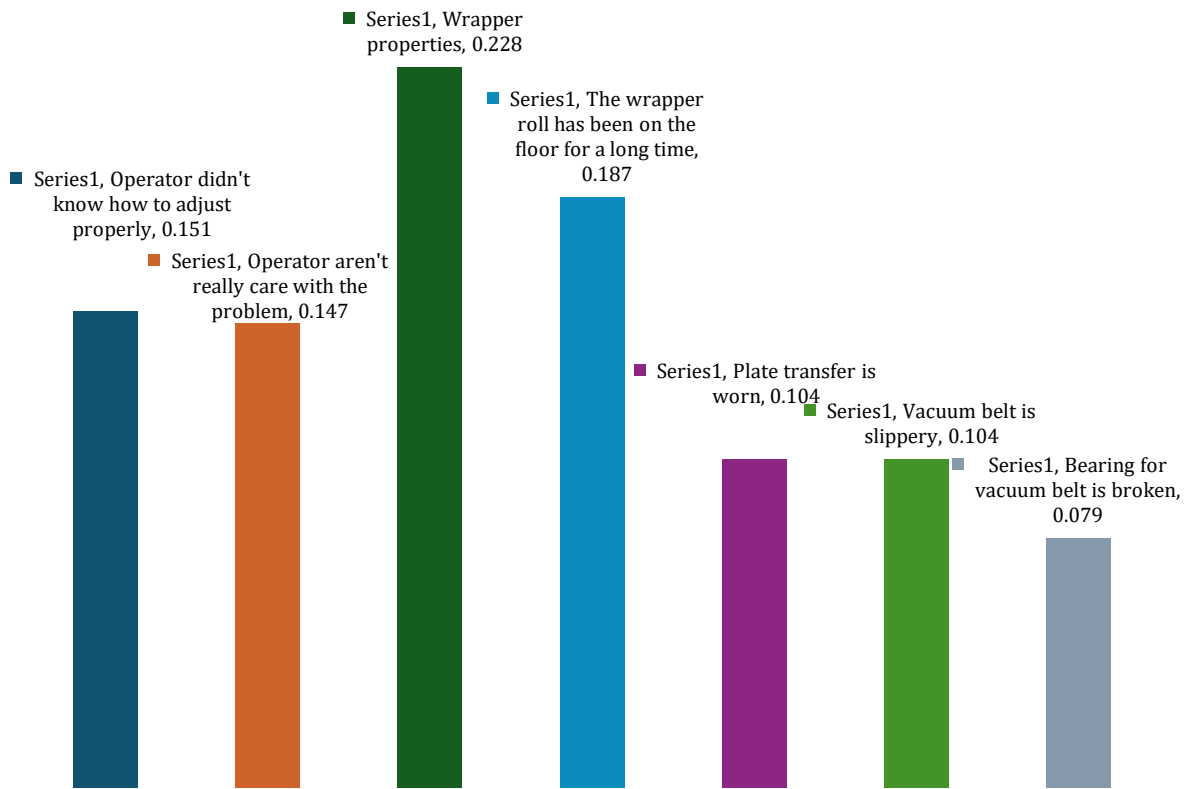


Fig. 3 Weight of sub criteria and the expert opinion for the alternative of wrapping alignment issue

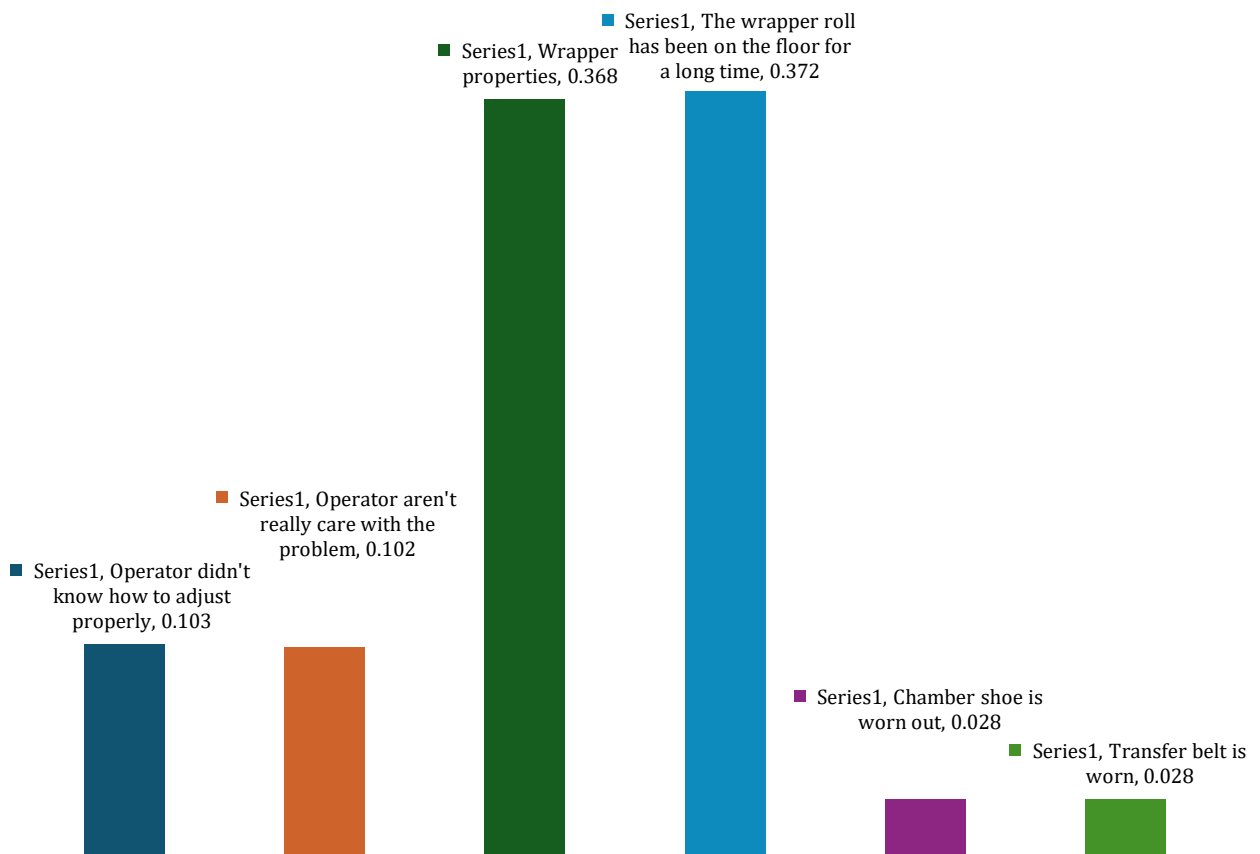


Fig. 4 Weight of sub criteria and the expert opinion for the alternative of bad folding issue



Problems with wrapper properties, plate transfer worn, vacuum belt slippery, broken vacuum belt, chamber shoe worn, and transfer belt worn were caused by the lack of operator ability to operate and maintain the machine. To overcome this problem, a training program is needed. A maintenance checklist needs to be prepared to help the maintenance process. The wrapper roll that has been on the floor for a long time can be overcome by preparing Standard Operating Procedures (SOP). It can be concluded that three action plans are needed: (A) Prepare the training sessions, (B) Create the Standard Operating Procedures (SOPs), and (C) Create the comprehensive checklists.

SOP is an important document in quality measures and evaluation. It is an essential pre-requisite for any Quality initiative. SOP has the potential to improve quality without increasing cost. SOP also has many other advantages such as maintaining product consistency, improving safety, saving costs and time, simplifying worker management, avoiding loss of knowledge due to worker turnover, and simplifying the audit process. So, the preparation and use of the correct SOP is not only useful for reducing defects that occur but is useful for improving overall company performance. However, writing SOPs requires certain skills and paying attention to many things. SOPs must be written based on practical prospects, from the perspective of the person using them. SOPs must be written in a step-by-step format, concise and clear. SOPs must be written in active sentences by emphasizing the main idea at the beginning of the sentence. SOPs must also not contain ambiguity.

On the other hand, training is not only useful for improving skills in overcoming defects, but psychological training will raise morale and work enthusiasm because workers will feel that they are very valuable. In addition, training also grows a greater sense of responsibility for their work. Training programs must be designed based on assessment and understanding of employee needs, skill sets and learning objectives. Training programs must have a clear plan on the methods used and the expected outcomes. The success of the training program needs to be measured for future improvements.

The checklist is an essential document for doing maintenance work in the industry. Checklists also play a role in overcoming defects by reducing errors and increasing efficiency and productivity. It is used as a guide for the technician in carrying out an intervention. It is also a means of collecting useful information used by maintenance managers and superiors for operation analysis. The maintenance checklist must be written based on the needs of the user in carrying out the work. Writing a checklist requires not only knowledge of the business and the equipment but also information gathered from the workers who will be doing the work. The workers are the users of the checklist, so the checklist must be in accordance with their needs regarding content and form. The use of digital format is often beneficial because it can be accessed from anywhere.

The degree of importance of the action plan found using Fuzzy AHP is shown in Fig. 5 for wrapping alignment issues and Fig. 6 for bad folding issues. For bad folding issues, creating a checklist was prioritized, followed by creating SOPs and training. Regarding wrap alignment issues, all action plans have similar priorities, with SOPs slightly higher than the others. The three action plans were obtained using systematic steps, as suggested in the methodology section. The systematic steps used helped to obtain an action plan to overcome the problem by prioritizing the most urgent problems (the problems caused defects beyond UCL and LCL permitted limit). The action plan obtained in this systematic way will be an action plan that is right on target. Therefore, it will accelerate problem-solving and saving time and investment. However, the effectiveness of the action plan must be tested by comparing the number of defects before and after the action plan is executed. This comparative data is needed for future improvements.

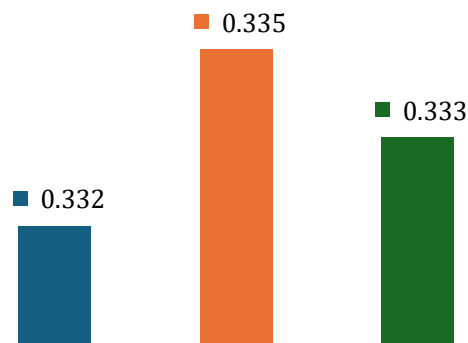


Fig. 5 The alternative decision score for wrapping alignment issues

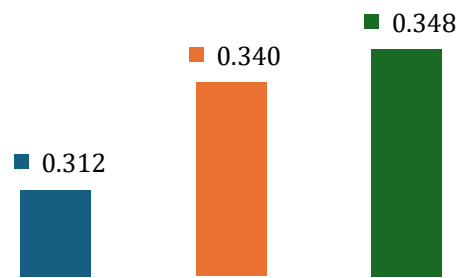


Fig. 6 The alternative decision score for bad folding issue

4. Conclusion

The problem of defects in a paper factory is tried to be solved by using Statistical Process Control to control production to comply with specific limits, and Fuzzy Analytical Hierarchy Procedure used to find the priority of the problem, and an action plan is proposed in this study. The data collected showed the paper company had several problems, with wrapping alignment and folding sheets being the main ones. From the analysis, it was found the problems were caused by several things, with wrapper properties and the length of time the wrapper rolls on the floor being the main causes. Therefore, to overcome the causes of the problems, three action plans need to be taken: training, creating SOPs, and creating maintenance checklists.

The results of this study underscore the critical significance by case study company's action plans for wrapping alignment and bad folding issues were creating SOPs. It was clearly articulated the Standard Operating Procedures (SOPs), the systematic maintenance schedules and continuous training to increase operator competency, foster attentiveness, and guarantee optimal machinery functionality for enduring enhancements in continuous quality improvement. Future investigations ought to examine the scalability and adaptability of this integrated SPC-Fuzzy AHP framework across a variety of paper converting processes, assess the implications of real-time data integration for dynamic modifications, and explore the formulation of automated systems that convert prioritized action plans into prompt operational alterations. Hence, it can enhance production efficiency and quality control to evaluate the optimal machine performance for sustained quality improvements.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Anita Susilawati, Rolandi; **data collection:** Rolandi; **analysis and interpretation of results:** Anita Susilawati, Rolandi; **draft manuscript preparation:** Anita Susilawati, Rolandi. **improve the manuscript quality:** Anita Susilawati, Adek Tasri. All authors reviewed the results and approved the final version of the manuscript.

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