



# Applications of Analytical Hierarchy Process (AHP) and Knowledge Management (KM) Concepts in Defect Identification: A Case of Cable Manufacturing

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

Compromised Insulation thickness of a cable product is essentially linked to several quality problems ranging from energy leakage, electric shocks and increased chances of electrocution incidence, loss of customer goodwill, difficulty in product usage, material waste, etc. However, identifying the cause of this extrusion defect is a lengthy process due to complexities in extrusion coating processes and its economic effect is harsh on organization's financial bottom line. The extrusion complexities and the financial implications of compromised cable products require the need for a systematic decision approach in identifying vital defect causes for proper containment. A multi-criteria decision-making approach-AHP was deployed to solve similar real-life quality problems in cable manufacturing. With the aid of the decision technique, a hierarchy of decision was modeled and defect causes were properly identified and prioritized based on the members aggregated judgments on Insulation thickness failures. The technique has helped the case organization in having a deeper understanding of their process by guiding the interest of their improvement team towards vital defect warnings while acknowledging the possible influence of the trivial many.

*Keywords: Analytic hierarchy process; multi-criteria decision making; defect; insulation thickness; cable.*

## 1. INTRODUCTION

Most organizational decisions are based on a subjective level due to top-down hierarchical information flow. AHP offers a systematic decision approach whereby group perceptions on a particular topic are collated and weighed to a consensus conclusion. Sound judgments on a subject are likened to deep understanding / vast knowledge on the subject. AHP provides the enabling platform for the intersection of ideas through group activities and assignments. It is often assumed that the decision produced by a group will always be better than that supplied by an individual. This is plausible because multiple participants can bring differing expertise and perspectives to carry out any complex decision. In a complex situation involving multilevel actors with different aspects to be considered in multi-criteria decision-making processes are often used to solve and make an appropriate choice [1]. This problem-solving approach would be appropriate in cable manufacturing due to the complexities associated with extrusion processes and the obvious need for member's knowledge in solving a quality related problem. Quality problems in cable manufacturing need to be understood properly, its effects, influence and their criticalities carefully mapped out for adequate improvement responsibilities. The origin of extrusion defects is not always understood due to complexities in extrusion coating processes [2], but failures or defects which are normally occurring in cable extrusion process are due to three main causes; mould design, material selection and processing. Making defective products in cable manufacturing, even though they can all be recovered, re-ground and the material used again is uneconomic and non-productive because there is a large amount of money invested in the rejected product and extra energy and labour must then be spent on material recovery. It is best avoided since they directly reflect on the organization's financial bottom line. In cable manufacturing, observational studies are much and knowledge of the workforce is very vital in improvement studies. It is pertinent for organizations to capitalize on inherent group advantages in taking decisions that will affect the overall functionality of their production system. The expert's judgment is paramount in every complex process as a result of the associated multi-criteria elements. This paper will briefly

review the concepts and applications of the multiple criteria decision analysis, the AHP Implementation steps and demonstrate AHP application on defect reduction in cable manufacturing.

## 2. ANALYTIC HIERARCHY PROCESS CONCEPT

AHP is the most known multi-criteria decision making (MCDM) technique devised for solving complex management decision problems. The Analytical Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and depends on the knowledge of experts [3]. In business, AHP is typically used in contexts of uncertainty that require evaluating different alternatives based on qualitative and quantitative criteria [4]. It can be used to identify a single most preferred option or simply to distinguish acceptable from unacceptable possibilities. The Analytic hierarchy process has been applied in some fields of decision-making and its popularity has increased in recent years in manufacturing and industrial applications [5]. The technique was developed by [6] in 1980 and this technique share some conceptual similarities with other MCDM techniques like the Aggregated Indices Randomization Method, Analytic Network Process (ANP), Analytical Hierarchy Process (AHP), Balance Beam Process, Base-criterion Method (BCM), Best Worst Method (BWM), Brown-Gibson Model, Multi-Attribute Utility Theory (MAUT), Data Envelopment Analysis (DEA), fuzzy set theory, Case-based Reasoning, Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Artificial Neural Network (ANN), Simple Multi-Attribute Rating Technique (SMART), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), etc. However, the outstanding feature of the AHP technique is that it can deal with the qualitative and quantitative aspects of a decision-making problem [7]. AHP makes complex decision processes more rational by synthesizing all available information about the decision in a system-wide and systematic manner [8]. AHP techniques can measure the consistency and thus reduce the effect of subjectivity in the decision making process [9]. The AHP encourages group decision making, thereby allowing members of a group to make use of their experiences and knowledge to decompose a task into a hierarchy and solving it following the

AHP steps [10,11,12]. The AHP procedure involves the use of the following problem-solving steps according to [6]: Step 1: The hierarchical structure of the system is prepared, which entails identifying the elements of the system and grouping them in a hierarchical order that reflects functional dependence of one component to another. The second step: Comparative judgment is saddled with the making of paired comparison among elements at a given level, and the final step the priority analysis is basically for normalization and examination of consistency. The method has been used in a wide range of decision settings: to determine the best alternatives in terms of company valuation methods in legal asset inventory expertise [13]; in construction management domain for material and project selection [14,15,16,17] in health sector, [18,19,20,21,22,23,24] in manufacturing [25,26]. Recently this technique has been integrated with other multi-criteria decision tools like the TOPSIS, ANP; Fuzzy set etc. to achieve more convincing results. In other words, its fuzzy extension has been richly explored as found in extant literature to cater for the limitations attributed to the lone AHP approach.

### 3. CASE PRESENTATION

The unit of analysis under study is a medium-sized cable manufacturing company that is into the making of various sizes of cables in southeast Nigeria. Based on the case organization's evidence, solutions to problems in extrusion processes are not often sustained due to the outsourcing of the improvement function to the external consultants/experts most of the times. The resultant effect now becomes a challenging issue and the organization is thinking of adopting a new improvement strategy that will help avert silos effects in their production system. An attempt to ameliorate this production odd consequences mentioned earlier necessitate the quest for the organization to institute a knowledge-based social structure "the Community of Practice" (CoP) for the multi-criteria decision making. There are many types of defect in cable manufacturing processes, but for a matter of simplicity the defects were broadly grouped under two nomenclatures; Insulation Thickness Failures and Insulation Surface flaws. These two defects affect the homogeneity and the integrity of the polymer film and are always found in the customer's complainant record. The research focus of this study is on the Insulation thickness failures and how AHP techniques can

be used to prioritize defect causes within the subject nomenclature for possible elimination.

#### 3.1 Step 1: Cop Formation

The first step starts with formulating a team associated with the process. The underlying philosophy of this CoP formation is based on informal knowledge representation in tacit order, and also on the wealth of information needed in building a judgmental model.

The knowledge process model as described in Fig. 2 shows how organizational knowledge is enriched as each member of the unified group of Cop becomes more knowledgeable on chosen projects through the knowledge dynamics processes in a Cop environment.

Fig. 3 depicts the knowledge dynamism in group interaction and how it can benefit organizational goal. The potency of the CoP formation was explored and became the primordial strategy for rightful decision making in the industrial setting. The Cop interaction as described in Fig.1 would create knowledge spiral whereby tacit knowledge of member group involved in the improvement studies is made explicit. During the improvement study, knowledge is created, shared and are often located within the cognitive domain of the members involved in the improvement function. Knowledge at this stage is seen as mobile team knowledge which is still transitory and can be lost due to many factors such as retrenchment, retirement etc. The Mobile Team Knowledge Orders (MTKO) is transferred to organizational knowledge through proper documentation and update on the Standard Operating Procedure (SOP) of the organization. However, the objective of the formulated team in this study was to develop common skills in AHP decision technique, as well as to harness knowledge and shared expertise among the participants. The AHP methodology and procedures were discussed with the team during the sessions, having streamlined the community's objectives; the aggregated team now followed standard AHP procedural steps as shown in Fig.1.

#### 3.2 Step 2: Modeling Decision Hierarchy

The application of AHP begins with a problem being decomposed into a hierarchy of criteria to be more easily analyzed and compared independently. The hierarchical model communicates much larger amounts of information in a comparatively short period and to reduce process complexity.

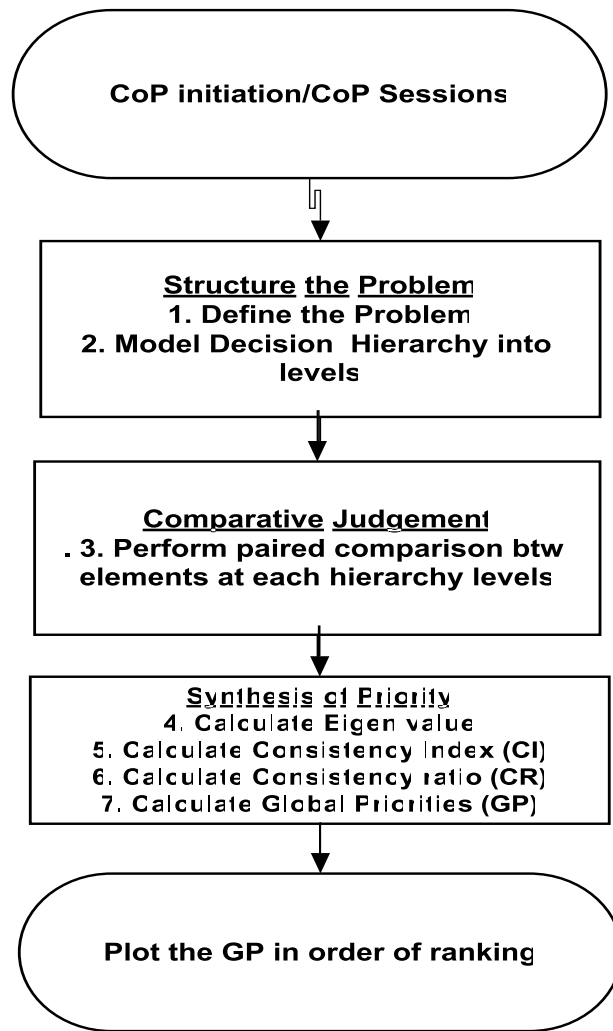


Fig. 1. A methodology flow process for the Analytic Hierarchical Process

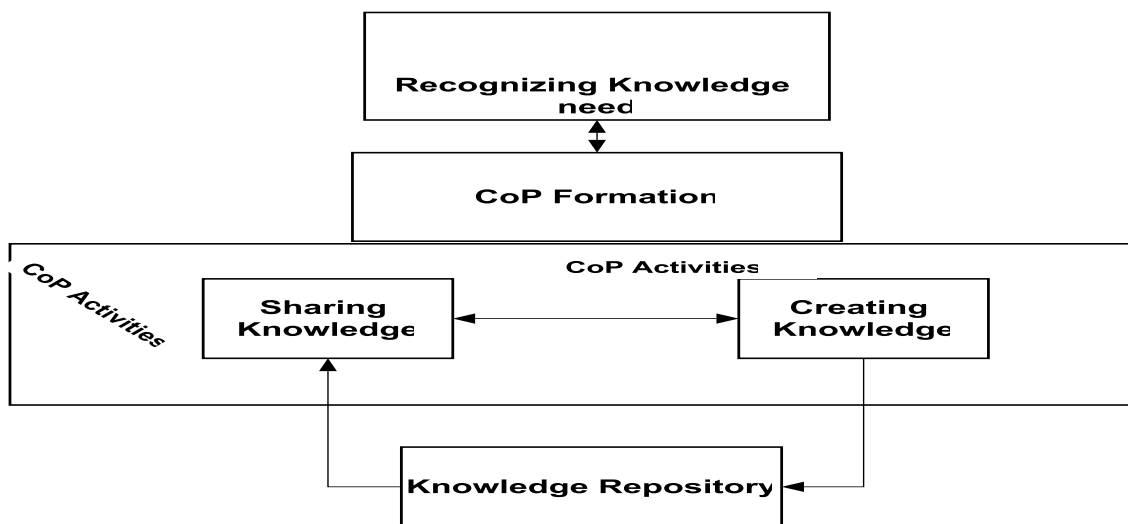


Fig. 2. Knowledge Management Process Model

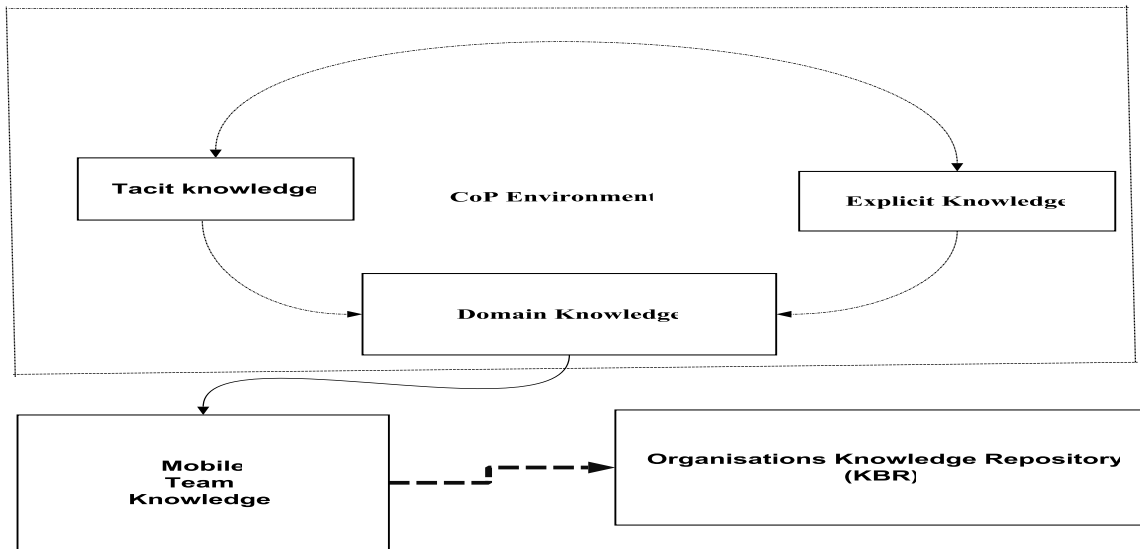


Fig. 3. Knowledge dynamics in CoP environment

### 3.3 Step 3: Comparative Judgment

Preferences in the AHP are determined based on pairwise comparisons, which involve the evaluation of each element with all the other elements at a given hierarchical level.

### 3.4 Step 4: Synthesis of Priority

The overall priorities can be made by synthesizing the judgment made in a pairwise comparison.

In making the pairwise comparison, a comparison matrix of the criteria involved in the decision is created. Weighting and adding are needed to come up with a single number to indicate the priority of each element [27]. In calculating the overall priorities, we used the eigenvalue method (EVM), as introduced by [6]. Let consider n elements to be compared,  $C_1 \dots C_n$  and the relative weight (significance) of  $C_i$  with respect to  $C_j$  by  $a_{ij}$ .

$$A = (a_{ij}) \text{ (be an } n \times n \text{ square matrix in which } a_{ij} = 1 \text{ for } i = j, a_{ij} = \frac{1}{a_{ji}} \text{ for } i \neq j.) \quad (1)$$

Such a matrix is said to be a reciprocal matrix, and the weights are consistent if they are transitive, that is;

$$a_{ik} = a_{ij}a_{jk} \quad (\text{for all } i, j \text{ and } k) \quad (2)$$

Let  $w$  be an eigenvector ( $n \times 1$ ) and  $\lambda_{max}$  be an eigenvalue

$$Aw = \lambda_{max}w \quad (3)$$

For matrices involving human judgment, the condition  $a_{ik} = a_{ij}a_{jk}$  does not hold as human judgments are inconsistent to a greater or lesser degree [11]. In such a case  $w$  vector satisfies the equation  $Aw = \lambda_{max}w$  and  $\lambda_{max} \geq n$ . The difference if any between  $\lambda_{max}$  and  $n$  is an indication of the inconsistency of the judgments.

$$C.I = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

$$(\lambda) = \frac{\sum W}{n} \quad (5)$$

where  $p$  = principal priority,  $w$  = weighted sum,  $C.I = 0$  for a perfectly consistent decision, but small values of inconsistency is tolerated if,

$$CR = \frac{C.I}{R.I} < 0.1 \quad (6)$$

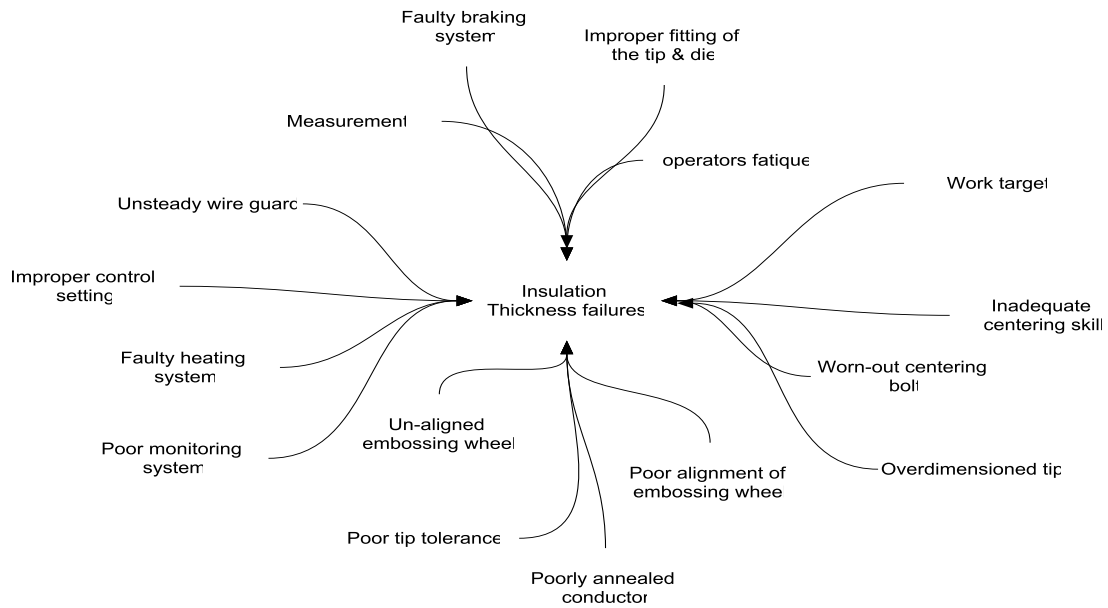
where  $R.I$  is the random index and is the average value of  $C.I$  for random matrices and is gotten from the random index  $f$ .

$$GP = S_{Cp} * C_p \quad (7)$$

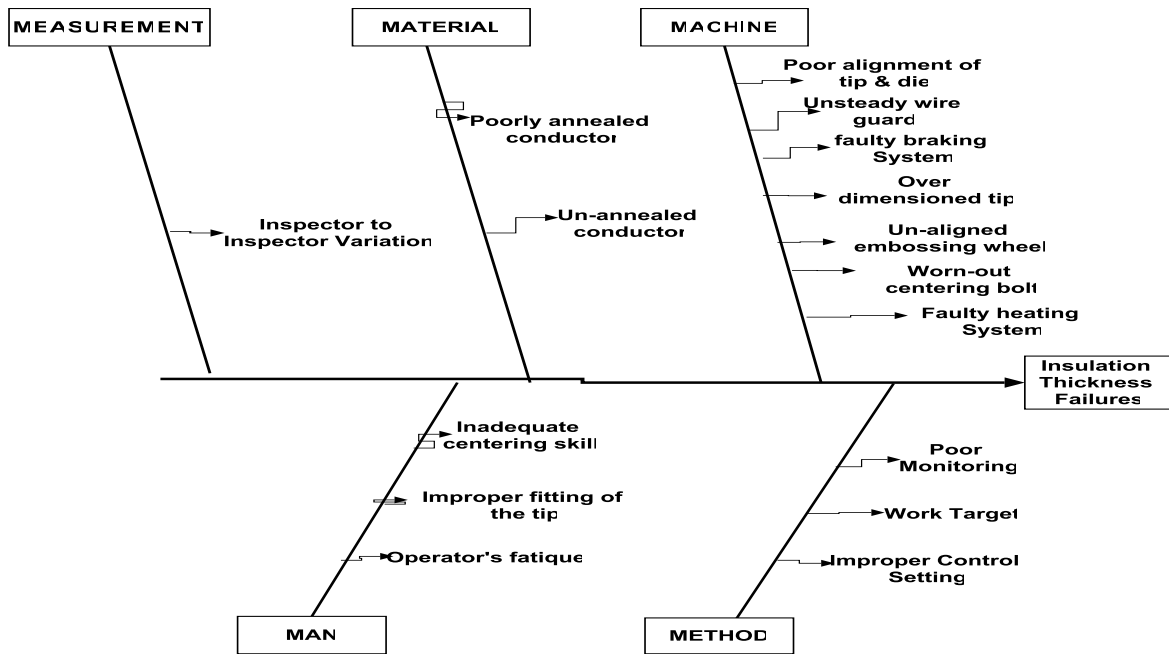
where  $S_{Cp}$  = sub criteria priorities, and  $C_p$  = criteria priorities.

## 3. RESULTS AND DISCUSSION

Pictorial representation in Fig.4 is the brainstorming diagram used during the brainstorming session. The brainstorming



**Fig. 4. brainstorming diagram of Insulation thickness failures and causes**

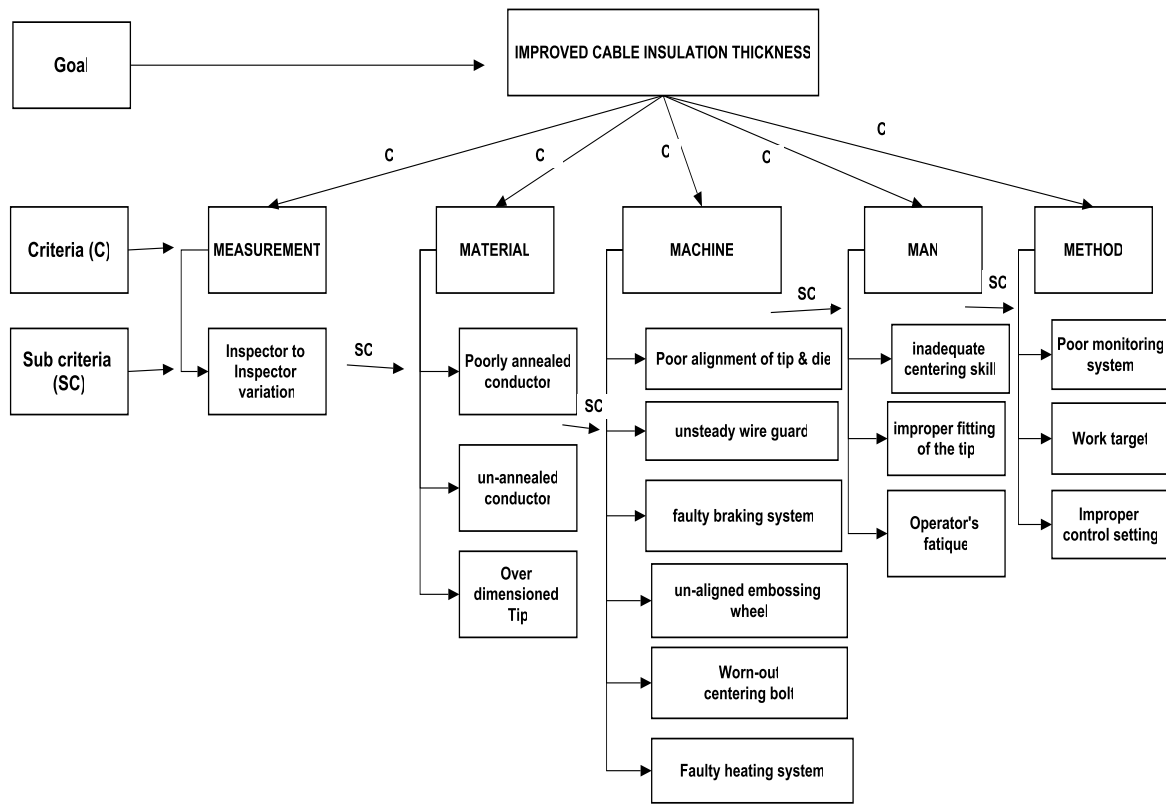


**Fig. 5. Cause and effect diagram on the cable insulation thickness failures**

session was initiated among the selected community to stimulate and unlocks the group's tacit knowledge of the process. This technique was potent in creating many solutions that were used to tackle the extrusion poor performance.

The brainstorming session was made more effective through the use of Fishbone diagram

and the results were arranged in rational categories. During the brainstorming session, the team enlists all potential causes to extrusion poor performance in terms of Insulation thickness failures. The Cause and Effect Diagram accurately displayed the relationships of all the data in each category and is pictorially represented in Fig.5.



**Fig. 6. Modeled decision hierarchy to improve cable Insulation thickness**

**Table 1. Main Criteria Comparison Table for the cable insulation thickness failures**

Name		Criteria		More Important	Intensity
i	j	A	B	A or B	(1-9)
1	2	Measurement	Material	B	7
1	3		Machine	B	3
1	4		Man	B	3
1	5		Method	B	3
2	3	Material	Machine	A	3
2	4		Man	A	5
2	5		Method	A	5
3	4	Machine	Man	A	3
3	5		Method	A	5
4	5	Man	Method	A	3

To analyze the decision of eliminating defects in the extrusion of primary cable, a judgmental model, known as the Analytical Hierarchy Process (AHP) was developed.

Analytical Hierarchy Process (AHP) was applied to prioritize the criticality of Insulation thickness defect causes. The first step was to model the decision by building a hierarchy for the decision. The developed model for the decision was decomposed into a hierarchy of goal, and criteria as seen in Fig.6. The goal of the study is to have a decision that will favour extrusion of cable with

improved insulation thickness. The second level of the hierarchy is the factors that can be altered towards achieving the study goal. In level 3, the sub-criteria/sub causes contain the sub causes that when altered affects the parent factor and then the principal goal. The Cop and a few other experienced personnel from the manufacturing department contributed to this stage of AHP, which is the pairwise comparison between every two sub-causes. The influence of one cause compared to the influence of the other causes on the generation of defects associated with Insulation thickness failures was judged. The

pairwise comparisons of the Insulation Thickness failures criteria were made and are as shown in Table 1.

The comparison matrix was normalized using the approximate method to obtain the local priorities vector as shown in Table 3.

The influence of one cause compared to the influence of the other causes on the generation of defects associated with cable Insulation thickness failures was judged. A comparison matrix was created and used to perform the pairwise comparison as shown in Table 2.

Table 3 contains the normalized values of the comparison matrix. The average value of each row is calculated from the normalized matrix Table 3 to obtain the local priorities of the main criteria. Local priorities of the main criteria are recorded in the seventh column of Table 3.

**Table 2. Pairwise comparison matrix with judgments for the five main criteria**

Criteria	Measurement	Material	Machine	Man	Method
Measurement	1	0.333	0.333	0.333	0.333
Material	3	1	3	3	0.5
Machine	3	0.333	1	3	0.5
Man	3	0.333	0.333	1	0.333
Method	3	2	2	3	1

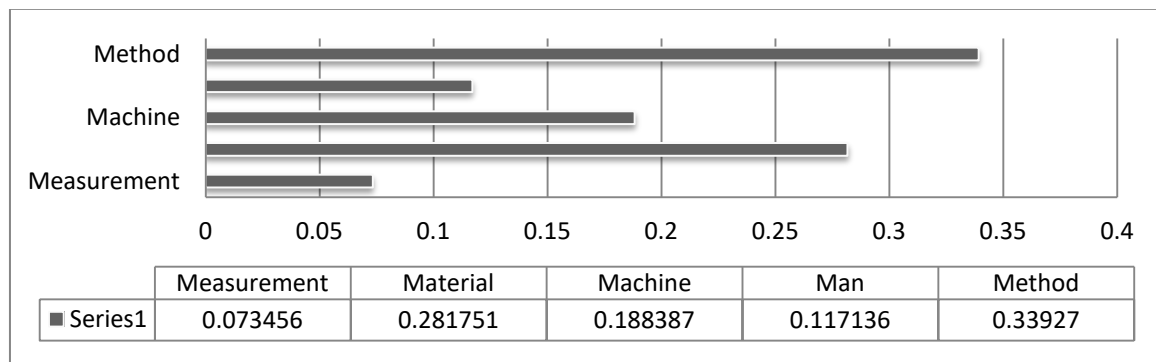
**Table 3. Normalized matrix for the principal eigen vector for the main criteria**

Criteria	Measurement	Material	Machine	Man	Method	Priority
Measurement	0.076923	0.083271	0.049955	0.032227	0.124906	0.073456
Material	0.230769	0.250063	0.450045	0.290332	0.187547	0.281751
Machine	0.230769	0.083271	0.150015	0.290332	0.187547	0.188387
Man	0.230769	0.083271	0.049955	0.096777	0.124906	0.117136
Method	0.230769	0.500125	0.30003	0.290332	0.375094	0.33927

**Table 4. Priorities as factors in weighing the main criteria**

Criteria	Measurement	Material	Machine	Man	Method	Weighted Sum
Measurement	0.073456	0.093823	0.062733	0.039006	0.112977	0.381995
Material	0.220368	0.281751	0.565161	0.351408	0.169635	1.588323
Machine	0.220368	0.093823	0.188387	0.351408	0.169635	1.023621
Man	0.220368	0.093823	0.062733	0.117136	0.112977	0.607037
Method	0.220368	0.563502	0.376774	0.351408	0.33927	1.851322

For the consistency check at the criteria level 1:  $\lambda = 5.382073$ ,  $C.I = 0.095518$ ,  $C.R = 0.088 < 0.1$  for  $n = 5$ ;  $R.I = 1.108$  (acceptable)



**Fig. 7. Graphical representation of criteria and their prioritized judgments**



Once judgments have been made, the next decision is to ascertain the consistency of the judgment. The AHP incorporates an effective technique for checking the consistency since the numeric values are derived from the subjective preferences of individuals, and it is impossible to avoid some inconsistencies in the final matrix of judgment. The weighted sum of all the criteria is as shown in Table (4) for onward consistency checks.

Fig.7 clearly depict the outcome of the criteria judgments with the Method criteria having the highest weight, followed by the material, and Measurement with the least criteria weight.

Next is to make a judgment about the sub-criteria at level 3. A paired comparison was made for the three (3) sub-criteria under Material, six (6) sub-criteria under Machine, three (3) under Man, and three (3) under Method. The measurement sub-criteria/subgroup has only one sub-criterion, so they were compared on how important they are for the measurement criterion. These sub criteria's were compared following the same pattern used for the level 2. Free web-based AHP software developed by [28] was used to run the analysis on level 3, due to computational rigours and iterative complexities.

The items in each group of sub-criteria have been pairwise compared and the result of the comparison now yields to the priorities seen in

the boxes in Fig.8. The priorities in each subgroup/sub-criteria sum up to one (1) and are referred to as the local priorities. At this juncture, all the comparisons for the criteria and sub-criteria have been made and the local priorities for each group at each level are as shown in Fig. 8. Sum of all the priorities at each level is equal to 1 ( $\sum C_p = \sum S_p = G = 1$ ).

where  $S_{Cp}$  = sub criteria priorities, and  $C_p$  = criteria priorities.

The priority of each criterion contributes to the priority of the goal and the priority of each sub-criterion contributes to the priority of its parents. Using equation (7), the global priority of each sub-criterion was derived as shown in the boxes in level 3 of Fig. 9. Based on the judgments entered by the Cop, and with the use of the AHP, factor priorities were derived and are shown from highest to lowest in Table (5) as well as in Fig. (10).

Fig.10) has shown the ranking of the nineteen sub causes, the aggregations of the decision-making group, pairwise comparisons are illustrated with the normalized weights. From this chart, we see that poor monitoring had the highest effect, and then the use of un-annealed conductor to improper control setting and so on till reaching the factor that had the lowest effect on the generation of Insulation thickness defect cables, which is the unsteady wire guard.

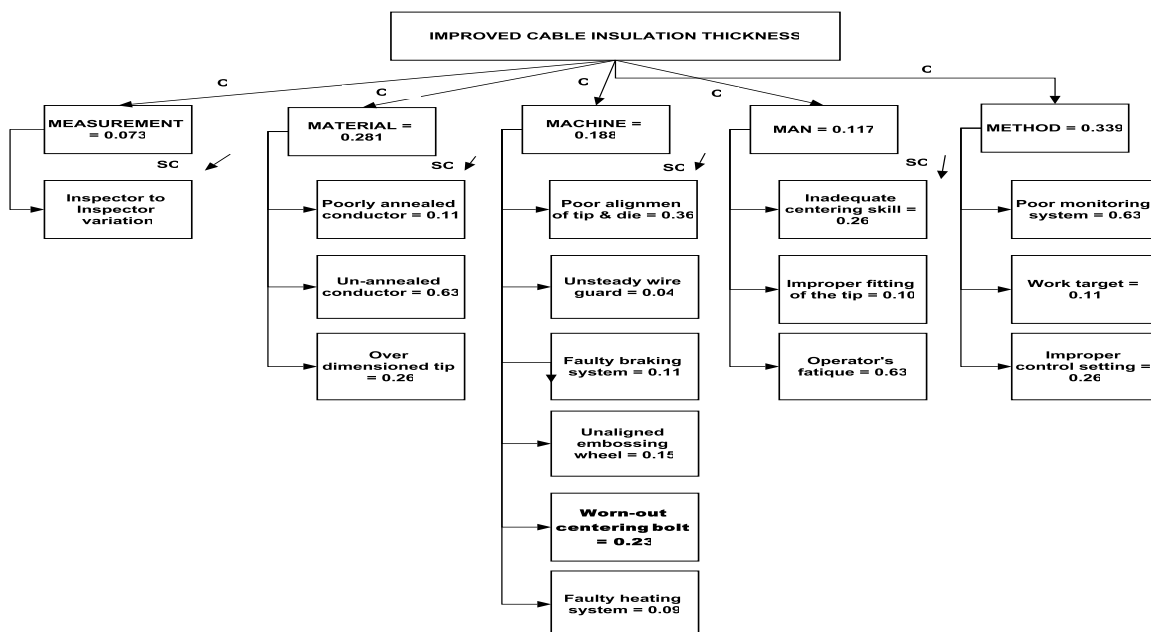
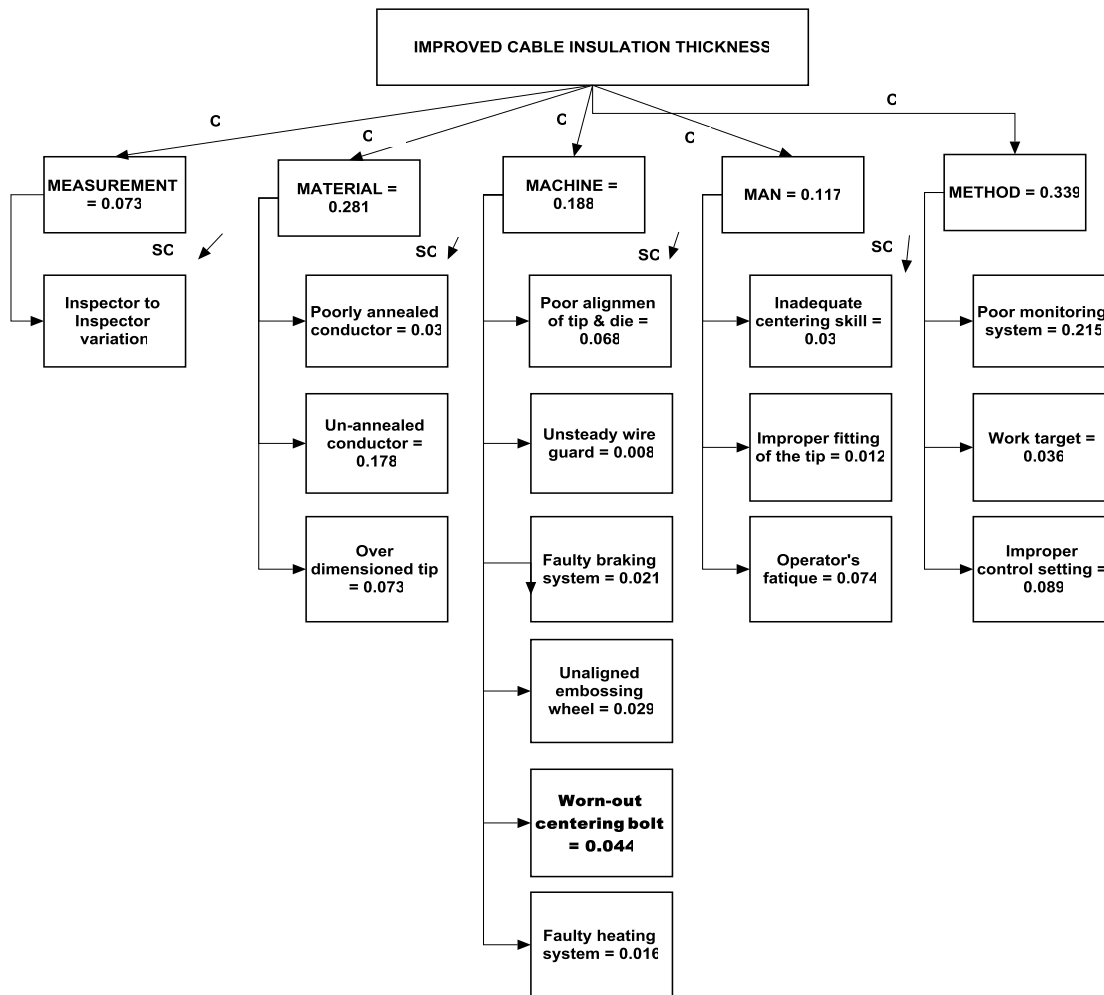


Fig. 8. Modeled decision hierarchy with the local prioritized judgments for the cable Insulation thickness



**Fig. 9. Modeled decision hierarchy with the global prioritized judgments for the cable Insulation thickness**

The 80-20 rule was used to recognize sub-causes/ sub-criteria that have the most influences on the generation of cables with failed Insulation thickness. As represented in the Fig. 11, the rule showed that eight sub causes account for 80% of the defects, and they are as

follows: poor monitoring, un-annealed conductor, improper control setting, and operator's fatigue, over-dimensioned tip, measurement, poor alignment of tip & die, and worn-out centering bolt.

**Table 5. Derived factor priorities for the improved cable insulation thickness**

S/N	Factors	Global priority	Factors	S/N	Global priority
1	Poor monitoring	0.215	Work target	9	0.036
2	Un-annealed conductor	0.178	Inadequate centering skill	10	0.03
3	Improper control setting	0.089	Poorly annealed conductor	11	0.03
4	Operator's fatigue	0.074	Un-aligned embossing wheel	12	0.029
5	Over dimensioned tip	0.073	Faulty braking system	13	0.021
6	Measurement	0.073	Faulty heating system	14	0.016
7	Poor alignment of tip & die	0.068	Improper fitting of the tip	15	0.012
8	Worn-out centering bolt	0.044	Unsteady wire guard	16	0.008

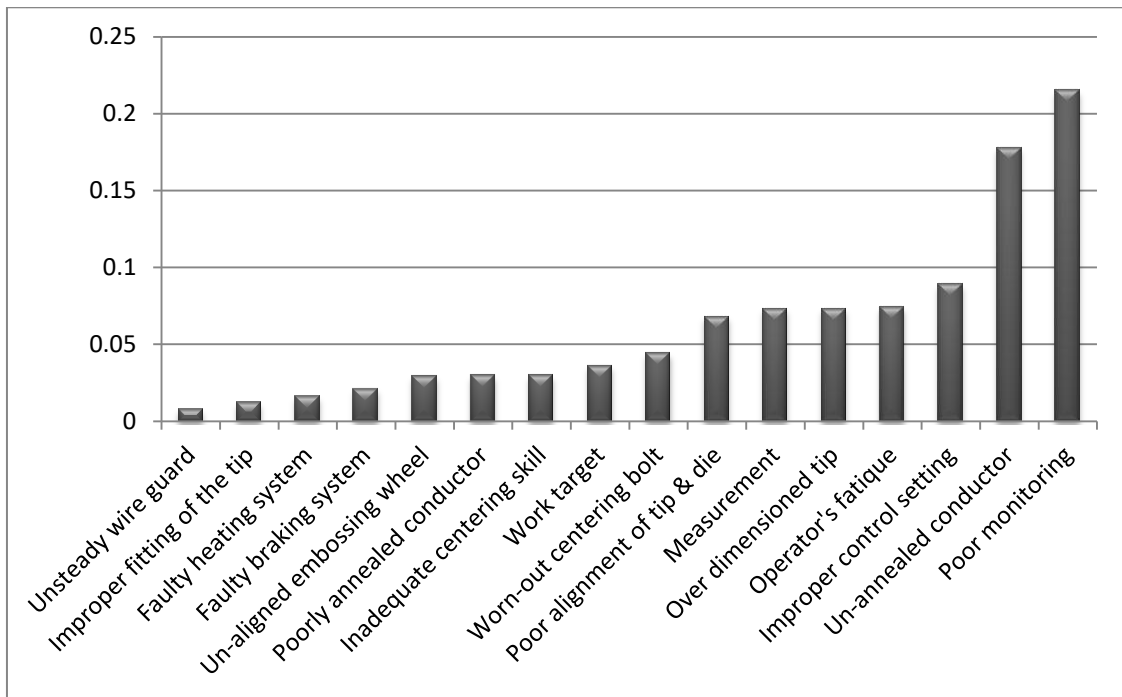


Fig. 10. Ranking of the sub-causes/ sub causes for improving Insulation thickness in a cable

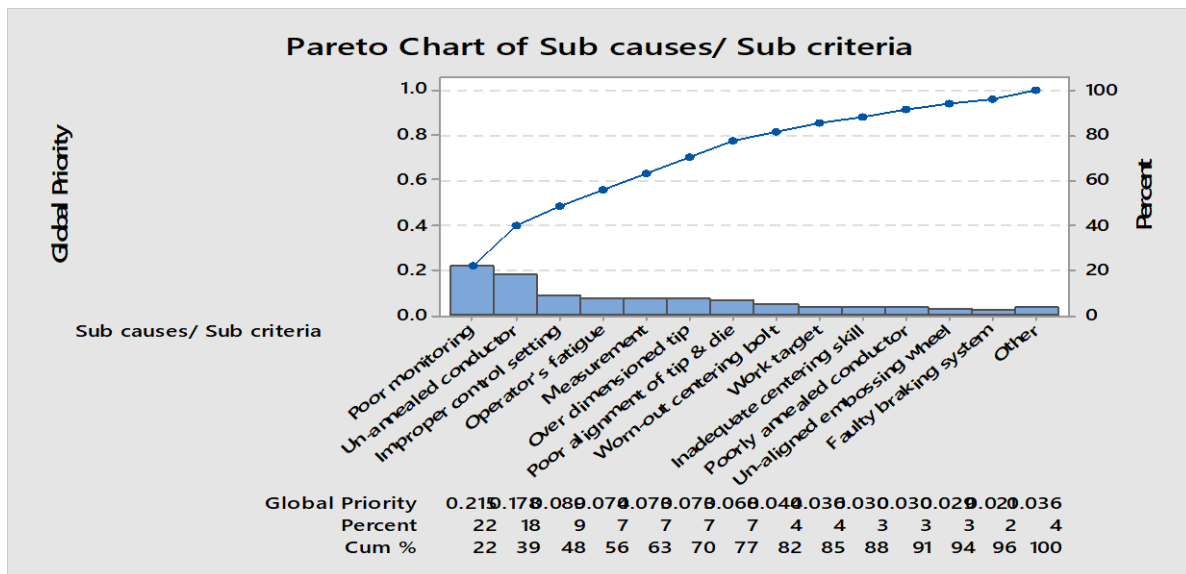


Fig. 11. Pareto Chart of sub causes of Insulation thickness failures

## 5. CONCLUSIONS

A systematic approach to evaluate quality in cable manufacturing has been developed using the analytical hierarchy process. The main purpose of this study was to screen defect causes in cable manufacturing using a systematic assessment of AHP. The outcome of the study will help cable manufacturing firms in choosing pro-active strategies for tackling the

quality problem in terms of resource allocation, machine maintenance, material selection, and manpower training, decision management, optimal parameter settings, initiation of the proper incentive program and introduction of realistic production target, adequate inventory management system, routine measurement system validation etc. The benefit of this study is not limited to an only person working in extrusion lines but for top decision managers for easy

identification and possible elimination of assignable causes of variation in an extrusion process. The AHP technique has proved to be a recommendable tool based on the subjective nature of the decision problem. This paper has industrial application and five (5) criteria and seventeen (17) sub-criteria have been identified as likely conditions for improving cable insulation thickness during extrusion processes.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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