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EVALUATION OF THE QUALITY OF AIR TEXTURED WARP YARN USING MCDM METHODS AND FUZZY LOGIC

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M.Sc. Thesis
in
Industrial Engineering
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Supervisor

Assoc. Prof. Dr. Eren ÖZCEYLAN

by
Umutgül BULUT
April 2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Umutgül BULUT

ABSTRACT

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The textile production process like many other industrial processes, involves the interaction of a large number of variables. The high degree of variability in raw materials, multistage processing and a lack of precise control on process parameters have resulted the lack of established relationships between raw material properties, process parameters and product properties has. One of the aforementioned challenges in warp yarn industry is the strength of the air textured warp yarn. It is a known fact that strength of textured yarn affects the product quality directly. Physical properties of air-textured warp yarn form the basis of yarn strength. Making a comparison between the parameters of physical properties and the values of quality standards, and avoiding yarn faults have been identified as multi-criteria decision-making problem for decision makers. The purpose and the scope of this thesis are to determine interaction between the criteria (count, tenacity, elongation, shrinkage, breaking force, RKM) that affects yarn quality and forms the basis of yarn strength, and identify the criteria weights with DEMATEL method which is a MCDM method, and ranking four type of products samples (800, 1100, 1350, 1600 Denier) from best to worst, to apply a quality classification with TOPSIS method. In order to eliminate uncertainty, fuzzy inference system is used as the scope of scenario analysis.
Key Words: Air Textured Yarn, Quality Control, Multi Criteria Decision Making, Fuzzy Inference System, Textile.

ÖZET

ÇKKV YÖNTEMLERİ VE BULANIK MANTIK KULLANILARAK HAVA TEKSTÜRE ÇÖZGÜ İPLİĞİNİN KALİTESİNİN DEĞERLENDİRİLMESİ
BULUT, Umutgül
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Tekstil endüstrisindeki üretim süreci, diğer endüstriyel süreçlerdeki gibi çok sayıda değişkenin etkileşimini içerir. Yüksek oranda hammaedde çeşitliliği, çok aşamalı işlenme ve işlem parametreleri üzerindeki kontrol eksikliği, değişkenler ve ürün özellikleri arasındaki ilişkinin kurulamamasına sebebebiyet vermektedir. Çözgü ipliği endüstrisinde sözü edilen zorluklardan birisi tekstüre ipliğin mukavemetidir. Tekstüre ipliğin mukavemetinin ürün kalitesini doğrudan etkilediği bilinen bir gerçektir. Hava tekstrüre ipliğin fiziksel özelleri iplik mukavemetini oluşturmaktadır. Bu fiziksel özelliklerin değerleri ve kalite standartlarına ait değerler arasında bir karşılaştırma yapmak ve iplik hatalarını önlemek karar vericiler için bir çok kriterlerli karar veme problemi olarak belirlenmiştir. Bu tezin amacı ve kapsamı; ipiliğin kalitesini etkileyen ve mukavemetini oluşturan kriterlerin (iplik numarası, denye başına kopma mukavemeti, kopma uzaması, çekme payı, kopma gücü ve kopma kilometresi) birbiri arasındaki etkileşimi ve kriter ağırlığını belirlemek için bir çok kriterli karar verme yöntemi olan DEMATEL yöntemini kullanmak ve dört farklı ürün tipine ait (800 Denye, 1100 Denye, 1350 Denye, 1600 Denye) örnekleri en iyiden en kötüye sıralamak ve bir kalite sınıflandırması yapmak için TOPSIS yöntemi kullanmaktır. Belirsizliği ortadan kaldırmak için seneryo analizleri kapsamında bulanık çıkarım mekanizması uygulanmıştır.

Anahtar Kelimeler: Hava Tekstüre İplik, Kalite Kontrol, Çok Kriterli Karar Verme, Bulanık Çıkarım Mekanizması, Tekstil.

"Dedicated to my family"

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LIST OFABBREVIATIONS

ATY	Air Textured Yarn
POY	Partial/Pre Oriented Yarn
TOPSIS	Technique of Order Preference Similarity to the Ideal Solution
DEMATEL	Decision-Making Trial and Evaluation Laboratory
FIS	Fuzzy Inference System
DTY	Draw Textured Yarn
ITY	Intermingled Textured Yarn
SEM	Scanning Electron Microscopy
MCDM	Multi Criteria Decision Making
AHP	Analytic Hierarchy Process
DEA	Data Envelopment Analysis
OWA	Ordered Weighted Averaging
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
GAIA	Geometrical Analysis for Interactive Aid
FPP	Fuzzy Preference Programming
GTMA	Graph Theoretical Matrix Approach
PSI	Preference Selection Index
ANP	Analytic Network Process
FAHP	Fuzzy Analytic Hierarchy Process
DEN	Denier
R&D	Research and Development
RKM	Resistance per Kilometer

CHAPTER I

INTRODUCTION

1.1 Introduction

Producing high quality products has become the most important fact of production processes in textile industry, as in many other industries. Producing quality products and services has taken its place as one of the establishment goals for businesses although before making profit, with the global competition, rapid development of technology and increasing in the importance of customer satisfaction. Consumers always expect that, their needs and demands will be met with the best and most appropriate way. Quality can be formed with the combination of facts that standardization, convenience, adaptation, innovation, optimum cost and satisfaction [1].

Yarn is used as raw material in every branch of textile industry, except for non-woven. For this reason the increase in the quality of yarn groups used as raw materials will increase preference of companies, as well as an increase of profit share and a decrease of production costs, with protecting interests of consumers. In this way, companies producing high quality yarn groups can increase their prefer ability and easily adapt heightened competition with providing the facts of quality, such as standardization, convenience, adaptation, innovation, optimum cost and satisfaction.

The air textured yarn produced from polyester fiber, used as warp yarn in carpet weaving industry. Warp and weft yarns are two sets of mutually perpendicular and interlaced yarns that result a formation of a woven carpet at the weaving process [2]. The long vertical yarns are the warp yarns, the horizontal yarns are the weft yarns of a finished fabric as shown in Figure 1.1.1.

The ATY does not reflect quality values, causes defects in the carpet during or after the weaving process. Carpet manufacturers preferably work with suppliers as producing ATY who has achieved a certain quality standard and constantly improving their quality, to avoid these defects. Companies producing ATY that improve their quality in every process of production line, from raw material to finished goods, will provide priority in a strong competitive environment.

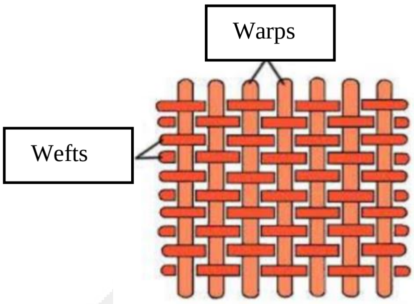

Figure 1.1.1 The weft and warp yarns [2]

The ATY is produced from POY (Poly Oriented Polyester Yarn) and used in the production of a woven carpet. Warp and weft yarns are two main components, used in weaving process, to turn yarn into fabric. The warp yarn is the set of yarns stretched in a place on a loom, before interworking of weft yarns, during the weaving process. It refers to yarns running lengthwise between weft yarns, while weft yarns running widthwise between warp yarns of a finished woven carpet [3]. Different types of yarns, such as polypropylene yarn, polyester yarn, viscose yarn, cotton yarn, can be used alone or mixture of the yarns with each other, while producing warp yarn.

POY refers to multifilament and only partially stretched yarn. It is also known as Polyester Pre-Oriented Yarn. POY has generally low tenacity and less uniform structure due to its polymer structure and it cannot be used directly in any production process of textile products. It is textured to make it usable and add bulk to the yarn. This type of yarn can be used a base for the production of all types of textured yarn (ATY, DTY and ITY). Textured POY can be used in draw warping, for weaving and warp knitting of fabrics [4].

The techniques, that used to change the structure and volume properties of synthetic fibers, are called 'texturizing' process. Texturizing process results the improvements on the structure of the yarn. Advantages of texturizing process on yarn structure are;

- Uniform appearance
- High yarn stability
- High bulk
- High pilling resistance
- Reduced boiling water shrinkage
- Low and uniform package take-off tension

The effect of texturing process can be achieved by changing central tensions that consists yarn’s cross section to non-parallel form. The quality of textured yarn depends on the production conditions and the texturing method selected during the texturing process.

The air jet texturing method is one of the thermo-mechanical methods and based on the texturing technique that mixing filaments yarns with the help of compressed air. The method is most versatile in all texturing methods that results more blended filaments together during the application of the technique. It is purely mechanical method and cold air-stream is used in this technique to produce bulked yarns with low extendibility.

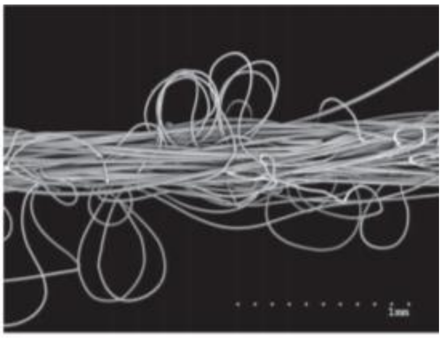

Figure 1.1.2 SEM image of typical ATY [5]

For producing a range of fabrics from the same warp, yarns are used with a variety of fillings. Air textured yarns have more compatible structure than other filament or spun yarns. Figure 1.1.2 represents the physical structure of ATY. Therefore using ATY, as raw material in the production process, is preferable for carpet manufacturers, because of its yarn characteristics. Characteristics of ATY are [6];

- A natural appearance and touch
- Good uniformity
- A unique appearance, hand and texture
- Increased physical bulk
- High abrasion resistance
- A subdued luster

Quality of air texture yarn can be tested with the judge of the look appearance of the yarn. Regularity of the yarn, loop size, luster and softness of the yarn and broken filaments are the characteristics that can be observed by the look appearance of the yarn. But those yarn characteristics are subjective and can be different from one person to another. Tests are listed below are evaluated to get more qualified physical properties:

- Linear density
- Boiling water shrinkage
- Loop stability
- Tenacity and break elongation
- Test knit and dye

1.2 Aim of the Thesis

Air textured warp yarn forms the length of the carpet to be produced, any yarn that does not fulfil the quality values causes defects on the carpet, such as elongation, shortening, stretching, shrinkage and irregularity problems. To avoid these defects carpet manufacturers, who use ATY as raw material, primarily prefer to work with ATY producers that provide quality standardization in every stage of production process.

Main specifications of the yarn are determined by the consumers, such as denier, number of filaments, crimp properties, nodes per unit length, minimum strength and elasticity required. Any yarn deviating from the specification will be rejected as poor quality. Machine parameter, parent yarn conditions and process parameter are the factors affecting the various properties of ATY. Under the same conditions, the properties of ATY can be defined with strength tests. A comparison can be made with the help of the tests evaluated, between test parameters and standard quality values. Thus provides that if the sample reflects the quality values, and avoiding yarn faults [7].

Making a classification about quality of yarns based on quality parameters can be a MCDM problem for ATY producers. A quality classification is also done with a FIS, based on physical properties and quality values of the yarn.

Aims of this thesis are, identifying interaction between the criteria, that affects yarn quality, and determining the criteria weights with DEMATEL method which is a MCDM method and ranking yarn samples of a textile mill from best to worst with TOPSIS method. In addition to deal with uncertainty and identify a quality level for yarn samples, fuzzy inference system is used as the first part of scenario analysis, and to make a comparison about results TOPSIS method is evaluated again with equal weights of criteria

CHAPTER II

LITERATURE REVIEW

2.1 Literature review about MCDM methods used in textile industry

Various MCDM methods have been used to solve multi-criteria decision problems occur on manufacturing processes in textile industry and about industrial issues in the sector. Navel rotor spinning machine selection, directly affect the quality parameters of final yarn for denim fabric. Majumdar et al. [8] developed a model with AHP and TOPSIS method to solve navel rotor spinning machine selection problem. Saeidi et al. [9] developed an application for woven fabric defects problems, ranking defects with Data Envelopment Analysis (DEA) method.

For the selection of suitable spinning conditions for the weft knitting process, Fallahpour et al. [10] applied VIKOR method. Saeidi et al. [11] applied Ordered Weighted Averaging (OWA) method to rank fabric defects, for another fabric defect problem in textile industry.

Jia et al. [12] implemented a study about supplier selection problem in textile and clothing industry with using TOPSIS method. Acar et al. [13] used TOPSIS for ranking manufacturing performance in related years, of a company from a corporate group in textile industry, to ensure sustainable manufacturing performance.

For cotton fibre selection problem, Chakraborty and Bandhopadyay [14] used PROMETHEE II method to rank alternative cotton fibres, and Geometrical Analysis for Interactive Aid (GAIA) to support the derived selection decision. Subramaniya et al. [15] developed a new approach for identifying critical success factors to increase agility level in a textile industry, with using TOPSIS method.

Chakraborty et al. [16] presented a study based on DEMATEL and VIKOR method for ranking cotton fibre alternatives for another cotton fibre selection problem. Çakır [17] studied a methodology combining Fuzzy Preference Programming (FPP) Method and Graph Theoretical Matrix Approach (GTMA) for a textile company, to solve subcontractor selection problem. Patnaik et al. [18] studied PROMETHEE and

Preference Selection Index (PSI) method for ranking fiber reinforced composite materials. Mohsin and Sardar [19] implemented an approach, with using Analytic Hierarchy Process (AHP), to compare pad-dyeing and foam-dyeing technique with concerning cost, performance, productivity and environmental sustainability of dyes on cotton fabrics.

Wang et al. [20] studied Analytical Network Process (ANP), Fuzzy Analytical Hierarchy Process (FAHP) and PROMETHEE II method to solve another supplier selection problem in textile and garments industry. Recently TOPSIS used to solve critical and practical problems in the textile industry, as its advantage of providing alternative ranking and easy to use for optimal solutions. Bathrinath et al. [21] defined possible risks in textile industry that create accidents with AHP and TOPSIS method.

In literature there are several MCDM methods are used to solve different decision-making problems in textile industry, but there is no study about air textured yarn with the criteria affecting quality of the yarn. In this study, two different MCDM methods are practiced to solve quality classification problem, namely DEMATEL and TOPSIS method. Six factors affecting yarn quality are used as criteria for MCDM methods, weights of the criteria are identified with DEMATEL method. A data set is used that belong to a firm producing ATY and yarn samples are ranked from best to worst with TOPSIS method according to the weights evaluated with DEMATEL method. In order to make a comparison between the results obtained, TOPSIS method is applied again using equal criterion weights within the scope of scenario analysis.

2.2 Literature review about FIS approaches in textile industry

In literature; there are several fuzzy approaches have been successfully applied in textile industry. Majumbar and Ghosh [22] studied a fuzzy expert system for prediction of the tenacity of ring spun cotton yarns. Jeguirim et al. [23] evaluated fuzzy and neural models for the prediction of sensory properties from production parameters of knitted fabrics. Performances of the proposed models was developed with statistical criteria namely the root mean square error and mean relative percent error. Amindoust and Saghafinia [24] proposed a model for real-life supplier selection problem for a textile company in Malaysia with applying a modular FIS.

Haque et al. [25] developed fuzzy model for the prediction of whiteness index of single jersey cotton knitted fabric. The model evaluated with using MATLAB and generated by taking three bleaching process parameters as the input variables and fabric whiteness index as the output variable. Vu and Kim [26] studied FIS to develop a complete combination of the wearable application based on a textile sensor. Sarkar et al. [27] studied a fuzzy logic based model to predict the GSM and crease recovery angle of laser engraved denim in textile industry.

However there is no study about identifying a quality level of ATY, with using a fuzzy model in textile industry. This thesis is developed a quality level model for ATY samples, based on a FIS. The proposed model is evaluated with using the six physical properties of the yarn as inputs, 144 rules evaluated, different Mamdani membership functions for each different input, and as a result of ‘Quality Level’.

CHAPTER III

METHODS

3.1 DEMATEL

DEMATEL is a methodology that is used for researching and solving complicated and intertwined problem groups. It is firstly presented from Fontela and Gabus in 1974. The end of DEMATEL process is a visual representation of the impact relations map by which respondents organize their own actions in the world. DEMATEL method is used in MCDM field is to construct interrelations in criteria [28]. Main steps of DEMATEL method are summarized as follows [29];

Step 1: Generation of the Direct-Relation Matrix *(A)*

In *A* matrix, there are n numbers of evaluation criteria, and the relationship between the sets of paired criteria is evaluated to represent the direct effect that each *i*th criterion exerts on *j*th criterion that donated by an integer score. Equation (3.1.1) shows the structure of the Direct-Relation Matrix.

$$A = \begin{bmatrix} a_{11} \cdots & a_{1j} & \cdots & a_{1n} \\ \vdots & \vdots & & \vdots \\ a_{i1} \cdots & a_{ij} & \cdots & a_{in} \\ \vdots & \vdots & & \vdots \\ a_{n1} \cdots & a_{nj} & \cdots & a_{nn} \end{bmatrix} \tag{3.1.1}$$

Step 2: Development of the Normalized Direct Relation Matrix *(X)*

The normalized direct relation matrix *X* is developed from direct relation matrix *A* with Equation (3.1.2) and where k is shown in Equation (3.1.3).

$$X = k \cdot A \tag{3.1.2}$$

$$k = Min\left(\frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max\limits_{1\le j\le n}\sum_{i=1}^{n}|a_{ij}|}\right) \quad i, j \in \{1,2,3,...,n\} \tag{3.1.3}$$

Step 3: Development of the Total-Relation Matrix *(T)*

The total-relation matrix is developed with Equation (3.1.4), where I is an identity matrix. The element of t_{ij} is represents the indirect effects of *i*th criterion on *j*th criterion and the total relationship matrix reflects the total relationship between each pair of evaluation criteria.

$T = [t_{ij}]_{nxn}$, $i\ j = 1, 2, \ldots, n$

$T = X + X^2 + X^3 + \ldots + X^k$

$= X(1 + X + X^2 + \ldots + X^{k-1})[(1 - X)(1 - X)^{-1}]$

$= X(1 - X^k)(1 - X)^{-1}$

Then;

$T = X(1 - X)^{-1}$, when $k \to \infty$, $X^k = [0]_{nxn}$

$$T = X(1 - X)^{-1} \tag{3.1.4}$$

Step 4: Calculation of the Sums of Rows and Columns Matrix T

From the sums and columns are computed and denoted with the vectors of D and R, evaluated with Equation (3.1.5) and (3.1.6).

$$D_i = [\sum_{j=1}^{n} t_{ij}]_{nx1} = [t_i]_{nx1} ,\ i = 1,2,\ldots,n \tag{3.1.5}$$

$$R_j = [\sum_{i=1}^{n} t_{ij}]_{1xn} = [t_j]_{nx1} ,\ j = 1,2,\ldots,n \tag{3.1.6}$$

Step 5: Set a Threshold Value (α)

The threshold value (α) is developed from the average of the elements in matrix T and determined with Equation (3.1.7) where N is the total number of elements in matrix T.

$$\propto = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n}[t_{ij}]}{N} \tag{3.1.7}$$

Step 6: Development of Casual Diagram

A casual diagram can be evaluated by mapping the dataset of (*D*+*R*, *D*-*R*) where the horizontal axis (*D*+*R*) is calculated with adding *D* to *R*, and the vertical axis (*D*-*R*) is calculating with subtracting *R* from *D*.

Step 7: Weights of Criteria Calculation

Weights of each criterion is calculated with Equation (3.1.8)

$$W_{ia} = \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2}$$

$$W_i = \frac{W_{ia}}{\sum_{i=1}^{n} W_{ia}} \quad (3.1.8)$$

3.2 TOPSIS

TOPSIS is the short abbreviation of Technique for Order Preference by Similarity to Ideal Solution and it is presented by Hwang and Yoon in 1981. It is the one of multi-criteria decision-making method and based on an approach that chosen alternative should have the shortest distance from the Positive Ideal Solution and farthest distance from the Negative Ideal Solution [30].

One of the advantages of TOPSIS is its simplicity to carry out. It can be implemented at the same amount of steps regardless of the problem size or problem type. Thus has allowed a quick utilization to review other methods or to stand its own as a MCDM tool. Besides the advantages of the method, keeping consistency on judgment can be difficult for identifying weight attributes [31]. TOPSIS can be implemented in 7 main steps [32] :

Step 1: Decision matrix construction

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \quad (3.2.1)$$

In A_{ij} Matrix *m* represents the number of alternatives where *n* represents the number of criterions. Alternatives are listed horizontally as columns of the matrix and criterions are listed vertically as rows of the matrix and shown in Equation (3.2.1).

Step 2: Normalized decision matrix construction

Normalized values are calculated by dividing each center values by the norm of the total outcome vector. Equation (3.2.2) and Equation (3.2.3) shows the structure of normalized decision matrix.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \quad (3.2.2)$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \quad (3.2.3)$$

Step 3: Weighted normalized decision matrix construction:

Weighted normalize values are calculated by multiplying normalized decision matrix by its associated weights (w_i) . $(\sum_{i=1}^{n} w_i = 1)$. Equation (3.2.4) shows the structure of the matrix.

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \dots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \dots & w_n r_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ w_1 r_{m1} & w_2 r_{m2} & \dots & w_n r_{mn} \end{bmatrix} \tag{3.2.4}$$

Step 4: Determine the positive and negative ideal solutions

The positive and negative ideal solutions are calculated with Equation (3.2.5) and (3.2.6) to compare the alternatives with each other.

$$A^* = \left\{ (\max_i v_{ij} \middle| j \in J), (\min_i v_{ij} \middle| j \in J^{'} \right\} \tag{3.2.5}$$

$$A^- = \left\{ (\min_i v_{ij} \middle| j \in J), (\max_i v_{ij} \middle| j \in J^{'} \right\} \tag{3.2.6}$$

Step 5: Determination of the distance of each alternative to the positive ideal solution and negative ideal solution is calculated with Equation (3.2.7) and (3.2.8).

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \tag{3.2.7}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{3.2.8}$$

Step 6: Calculation of relative proximity is ensured with Equation (3.2.9).

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \tag{3.2.9}$$

Step 7: Ranking alternatives according to their relative proximity.

3.3 Fuzzy Inference System

FIS is a process based on the approach that mapping a set of given input variables to an output variable using fuzzy logic. In a complex system certain mathematical models are not qualified due to incomplete information and situations. Fuzzy set theory has developed to solve such problems that do not require certain boundaries. Fuzzy set theory can deal with uncertainty in real life, with describing mathematically and the help of functions [33]. Zadeh was first published fuzzy logic concept in 1965. A fuzzy set is a class of objects with continuum of grades of memberships. Such a set characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging between zero and one [34].

FIS is presented within the context of fuzzy set theory and one of the useful tolls to solve uncertainty and complicated problems depend on fuzzy logic [35]. The main structure of FIS is shown in Figure 3.3.1. The structure of FIS based on four main components;

1. A *fuzzification module* that translates crisp inputs into fuzzy values
2. An *inference engine* which implements a fuzzy reasoning mechanism to attain a fuzzy output
3. A *defuzzification module* to translate this latter output to crisp value
4. A *knowledge base* that comprises both fuzzy rules known as the rule base and membership functions known as the data base.

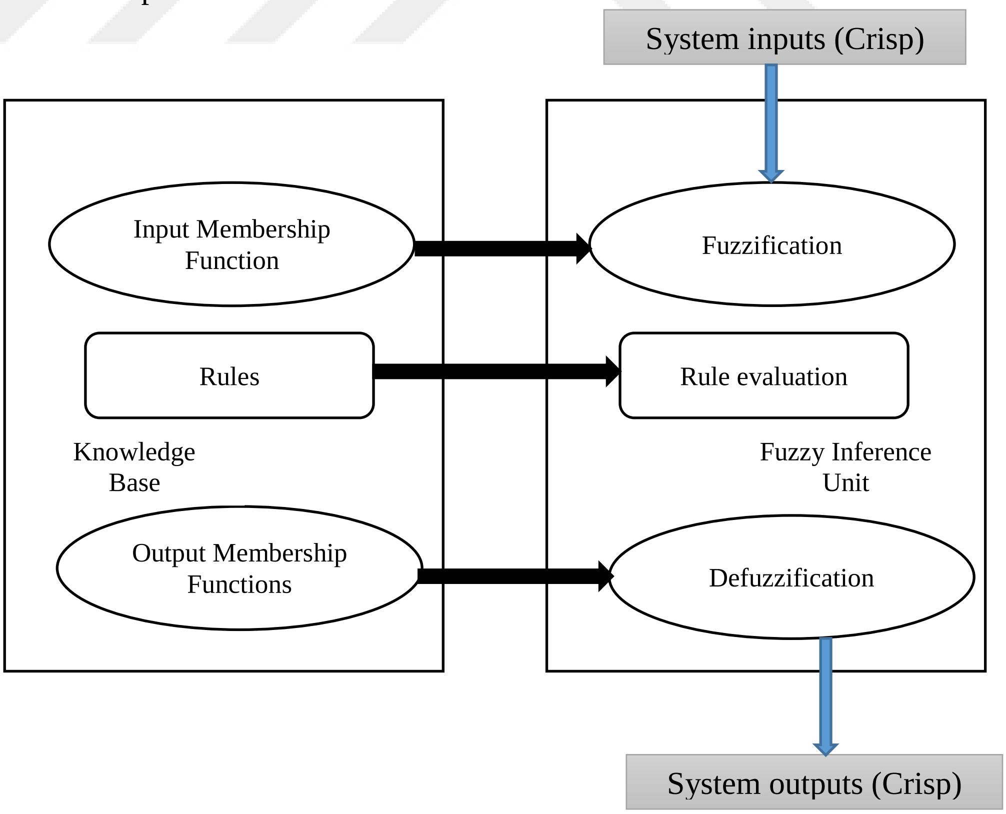

Figure 3.3.1 Structure of FIS [36]

CHAPTER IV

MATERIAL

This study is motivated from a textile mill producing ATY and established in Gaziantep. Objective of the study based on a model to solve quality classification problem of yarn samples. The company is built in Gaziantep in 25.000 m^2 production plant and producing five types of products which are Fibrillated PP Warp, Monofilament Landscape Yarn, Monofilament Sports Yarn, ATY Warp Yarn and ATY Weft Yarn. They aimed to produce high quality products to achieve a significant success in global market and adopted on customer satisfaction. They produce 4 types of ATY yarn with different deniers (800 DEN, 1100 DEN, 1350 DEN, and 1600 DEN). In a daily production, samples are randomly selected and subjected to tensile tests from quality control and R&D department of the firm with advanced technology testing equipment. Each yarn samples are tested with three different test procedures which are Tensile Strength Test, Thermo-Fisher Shrinkage Test and Thermal Resistance Test, as shown in Figure 4.1.

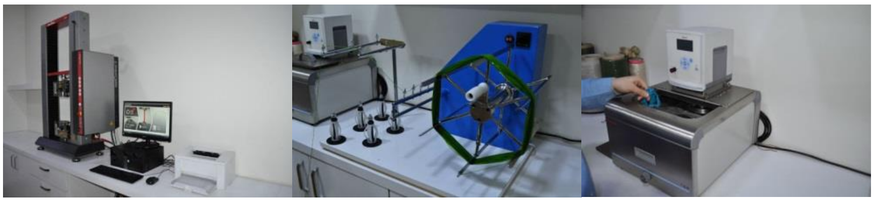

Figure 4.1 Tensile test procedures

Physical properties of the yarn, that are count, tenacity, breaking kilometer, breaking force and elongation are determined with elongation and strength test. Elongation and strength tests are provided with advanced extensometer named ZwickRoel and testXpert testing software. Shrinkage of the yarn is defined with Thermo-Fisher Shrinkage Test with silicon oil. Thermal resistance test is carried out to measure the heat resistance and change of the yarn samples after exposure to certain temperatures. After all testing procedures are completed physical properties of the yarn can be defined as yarn quality criteria with test parameters. Table 4.1 shows the terminology of yarn quality criteria and Table 4.2 is a short view of test results of 800 DEN ATY samples.

Table 4.1 Yarn Quality Criteria

Parameters	Description
Count	Count is expressed as the length per unit.
Tenacity	It is the breaking strength per denier.
Elongation	The ratio of extension of a specimen to its initial length, expressed as percentage.
Shrinkage	The decrease in length of a specimen cause by a specified treatment, expressed as a percentage of the length of the untreated test specimen.
Breaking Force	The maximum force applied to a test specimen carried to rupture during a tensile test.
RKM	RKM is the abbreviation of resistance per kilometer.

Table 4.2 Test results of 800 DEN ATY samples

Samples	Count	Tenacity	Elongation	Shrinkage	Breaking Force	RKM
S1	787.00	4.00	11.00	8.90	3.23	36.52
S2	820.00	4.60	14.50	8.80	3.71	40.37
S3	800.00	4.40	12.50	9.50	3.54	39.45
S4	823.00	4.40	13.10	9.10	3.54	38.31
S5	827.00	4.30	12.50	9.70	3.43	36.94
S6	815.00	4.30	13.00	9.10	3.45	37.80
S7	818.00	4.30	12.10	8.60	3.48	37.58
S8	793.00	4.10	11.70	9.10	3.25	35.34
S9	838.00	4.50	11.90	9.10	3.63	39.46
S10	829.00	4.30	12.40	9.40	3.40	37.47
.	.	.	.	.	.	.
S654	829.00	4.30	12.90	7.70	3.40	36.60
S655	812.00	4.00	12.20	7.40	3.23	33.71
S656	830.00	4.00	12.40	7.10	3.23	34.73
S657	825.00	4.20	13.10	7.90	3.37	36.36
S658	831.00	4.20	11.80	7.40	3.33	35.70
S659	829.00	4.20	13.30	7.20	3.39	36.50
S660	822.00	4.20	13.00	7.50	3.37	36.50
S661	831.00	3.90	11.90	8.20	3.10	33.22
S662	827.00	3.80	11.00	8.20	3.05	32.88
S663	830.00	4.20	12.40	8.00	3.36	36.00

CHAPTER V

CASE STUDY

5.1 MCDM Techniques for 800 DEN ATY

There are different yarn groups with different structure and physical properties [37], based on their usage areas in textile industry. Therefore quality of each different yarn groups is affected with different factors depends on their physical properties [38]. The physical properties of ATY namely count, elongation, shrinkage, tenacity are the factors that directly affect the quality of the yarn [7].

In a daily production of the textile mill, yarn samples are randomly selected and subjected to a series of tensile tests. As a result quality control department prepare a quality control report with the test variables of yarn samples. Making a comparison between test variables of yarn samples and quality standards can be a MCDM problem for ATY producers.

In this thesis MCDM methods (DEMATEL and TOPSIS) are used to solve quality classification problem. DEMATEL is applied to define the interaction between the criteria and identify the weights of the criteria, TOPSIS method is developed to rank yarn samples from best to worst. In this section MCDM techniques are applied for the data of 800 DEN ATY, and applications for 1100 DEN, 1350 DEN, 1600 DEN ATY are available in the appendices.

5.1.1 DEMATEL method for ATY samples

Since defining a quality classification for ATY samples with different test values is a truly complex MCDM problem, it is not appropriate to assume that the factors affecting yarn quality to be completely independent from each other. As all six criteria (six physical properties of ATY) are indispensable and significant it becomes essential to find out the importance level of each criterion for this evaluation problem and measure the relationships between various criteria. In order to achieve this DEMATEL method is used as a MCDM technique to analyze the relationship between these evaluation criteria. Since DEMATEL method has a narrow range while scoring the criteria with pairwise comparisons, it is practical and easy to develop. The six physical properties of the yarn are subjected as criteria of the DEMATEL method. The reason for choosing these structural properties as criteria is the company has measurable and real values with these evaluation criteria. The values of the test results of the evaluation criteria can be easily adapt and subject to the methods used.

Following the procedural steps of DEMATEL method the relationship between different evaluations criteria are scored using an integer scale between 0 and 4 shown in Table 5.1.1.1 while taking the opinions of three managers (quality control manager, operating manager and senior manager) of the firm, who are expert on their field. The managers are determined three different opinions among themselves, but the relationship between the criteria is established by making joint decision on a single opinion. Once the relationships between these criteria are measured, the initial direct-relation matrix (*A*) is subsequently developed as shown in Table 5.1.1.2 (where C1 is count, C2 is elongation, C3 is shrinkage, C4 is tenacity, C5 is RKM and C6 is breaking force). It is a 6 x 6 matrix, obtained by pair-wise comparisons.

Table 5.1.1.1 Integer score for DEMATEL method

Parameters	**Value**
No influence	0
Very low influence	1
Low influence	2
High influence	3
Very high influence	4

Table 5.1.1.2 Initial direct-relation matrix (*A*) of DEMATEL method

	C1	C2	C3	C4	C5	C6
C1	0	0	0	4	2	2
C2	0	0	1	0	1	2
C3	0	1	0	0	0	0
C4	4	0	0	0	2	2
C5	2	0	0	2	0	3
C6	2	0	0	0	4	0

From the developed direct–relation matrix (A), the corresponding normalized direct-relation matrix (X) is obtained in Table 5.1.1.3. Table 5.1.1.4 shows the total relation matrix (T). The sum of rows and sum of columns as represented by vectors D and R respectively are computed in Table 5.1.1.5. The threshold value is measured as α=0.5. The casual diagram, as shown in Figure 5.1.1.1, is subsequently developed while mapping the dataset of Table 5.1.1.6. The ($D + R$) and ($D – R$) values of Table 5.1.1.6 represent the total influence level for different evaluation criteria. Table 5.1.1.6 indicates that the criterion of *count* with the maximum ($D + R$) value has the largest total influence level, followed by the other five properties, i.e. elongation, shrinkage, tenacity, RKM, breaking force in this evaluation problem.

Table 5.1.1.3 Normalized direct-relation matrix (X) of DEMATEL method

	C1	C2	C3	C4	C5	C6
C1	0.00	0.00	0.00	0.44	0.22	0.22
C2	0.00	0.00	0.11	0.00	0.11	0.22
C3	0.00	0.11	0.00	0.00	0.00	0.00
C4	0.44	0.00	0.00	0.00	0.22	0.22
C5	0.22	0.00	0.00	0.22	0.00	0.33
C6	0.22	0.00	0.00	0.00	0.44	0.00

Table 5.1.1.4 Total relation matrix (T) of DEMATEL method

	C1	C2	C3	C4	C5	C6
C1	0.9831	0.0000	0.0000	1.1261	1.1523	1.0643
C2	0.3087	0.0122	0.1113	0.2339	0.4460	0.4893
C3	0.0340	0.1113	0.0122	0.0257	0.0491	0.0538
C4	1.2887	0.0000	0.0000	0.8205	1.1523	1.0643
C5	1.0105	0.0000	0.0000	0.8540	0.8609	1.0243
C6	0.8809	0.0000	0.0000	0.6235	1.0723	0.6848

Table 5.1.1.5 Computation of vectors D and R

	C1	C2	C3	C4	C5	C6
D	4.3258	1.6015	0.2862	4.3258	3.7497	3.2615
R	4.5059	0.1236	0.1236	3.6838	4.7329	4.3808

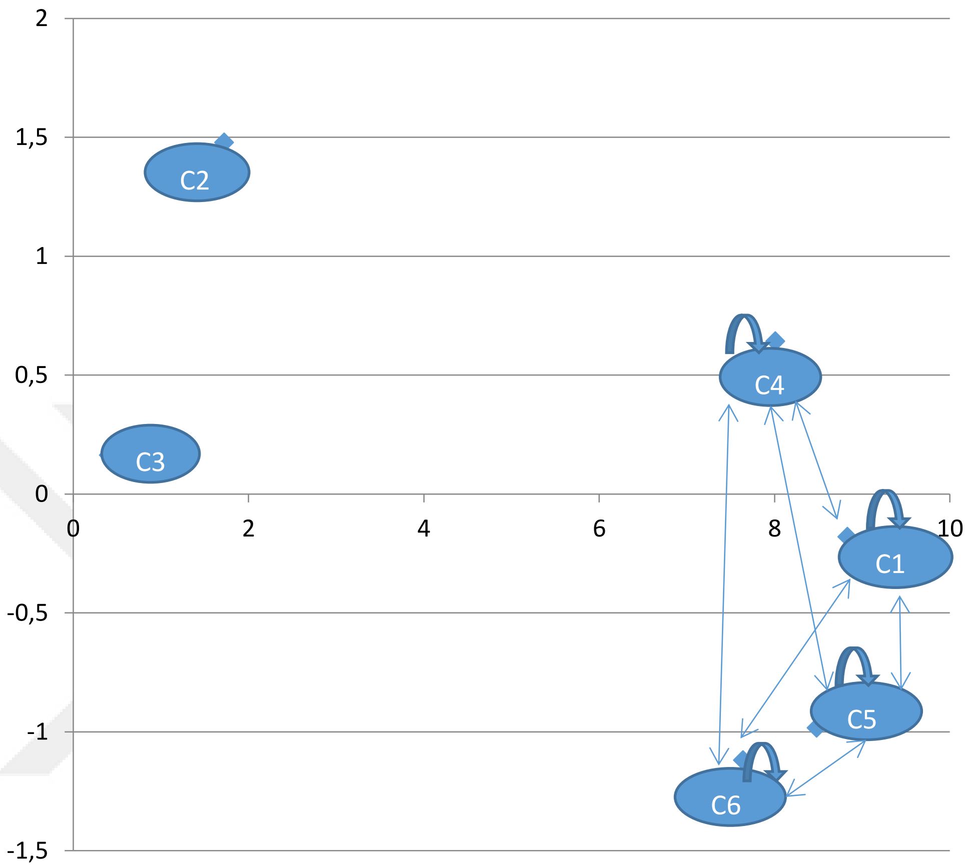

Figure 5.1.1.1 DEMATEL casual diagram of criteria

Table 5.1.1.6 Total and net effects for each evaluation criterion

Criteria	D+R	D-R	Weights	Rank
C1	8.8317	-0.1800	0.25	1
C2	1.7251	1.4779	0.06	6
C3	0.4098	0.1626	0.01	5
C4	8.0097	0.6420	0.23	3
C5	8.4825	-0.9832	0.24	2
C6	7.6423	-1.1192	0.21	4

Weights of the criteria and importance level of the criteria are found reasonable from the experts. After weights of criteria are found those weights are used for TOPSIS method to rank ATY samples.

5.1.2 TOPSIS method for ATY samples with DEMATEL weights

Since defining the weights of each criterion with DEMATEL method, TOPSIS method is used to define a quality classification for ATY samples. There are various techniques to for decision making problems to take decisions for many real time problems. TOPSIS is considered as one of the leading MCDM method that helps the decision makers to organize and carry out analysis to solve problems by comparing and ranking the alternatives [39]. In this thesis, once DEMATEL method is developed, TOPSIS method is evaluated subsequently to make a comparison between the test results and quality standards, and to rank the yarn samples from best to worst. There are 649 yarn samples subjected to tensile tests in six months production period. The 649 yarn samples with test results are assigned from A1 to A649 and listed horizontally, the six physical properties of ATY namely count, elongation, shrinkage, tenacity, RKM and breaking force are the criteria of TOPSIS method, assigned from C1 to C6, and listed vertically of decision matrix of the method as shown in Table 5.1.2.1. From the decision matrix construction normalized decision matrix is evaluated in Table 5.1.2.2. Table 5.1.2.3 represents the weights of the method which are defined with DEMATEL method. Weighted normalized decision matrix is shown in Table 5.1.2.4. The calculation of positive and negative ideal solution is obtained in Table 5.1.2.5 where A^+ is marked as the positive ideal solution and A^- is marked as the negative ideal solution. The distance of each alternative to the positive ideal solution and the distance of each alternative to the negative ideal solution are represented in Table 5.1.2.6 and Table 5.1.2.7 respectively. The relative proximity (C_i^*) is calculated in Table 5.1.2.8. Finally as it can be understood from Table 5.1.2.9 the best alternative A256 and the worst alternative is A366.

Table 5.1.2.1 Decision matrix of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
A1	787	11.00	8.90	4.00	36.52	3.23
A2	820	14.50	8.80	4.60	40.37	3.71
A3	800	12.50	9.50	4.40	39.45	3.54
A4	823	13.10	9.10	4.40	38.31	3.54
A5	827	12.50	9.70	4.30	36.94	3.53
.	.	.	.	.	.	.
A256	819	11.30	8.00	5.70	33.43	4.54
.	.	.	.	.	.	.
A366	794	10.40	8.50	3.60	31.47	2.86
.	.	.	.	.	.	.
A470	887	11.70	9.50	4.20	33.74	3.36
.	.	.	.	.	.	.
A617	860	24.40	7.70	4.40	36.46	3.49
.	.	.	.	.	.	.
A645	829	13.30	7.20	4.20	36.50	3.39
A646	822	13.00	7.50	4.20	36.50	3.37
A647	831	11.90	8.20	3.90	33.22	3.10
A648	827	11.00	8.20	3.80	32.88	3.05
A649	830	12.40	8.00	4.20	36.00	3.36

Table 5.1.2.2 Normalized decision matrix of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
A1	0.0370	0.0282	0.0398	0.0373	0.0393	0.0376
A2	0.0385	0.0372	0.0394	0.0429	0.0435	0.0432
A3	0.0376	0.0321	0.0425	0.0410	0.0425	0.0412
A4	0,0387	0.0336	0.0407	0.0410	0.0413	0.0412
A5	0,0388	0.0321	0.0434	0.0401	0.0398	0.0399
.	.	.	.	.	.	.
A256	0.0385	0.0290	0.0358	0.0531	0.0575	0.0529
.	.	.	.	.	.	.
A366	0.0373	0.0267	0.0380	0.0335	0.0339	0.0333
.	.	.	.	.	.	.
A470	0.0417	0.0300	0.0425	0.0391	0.0363	0.0391
.	.	.	.	.	.	.
A617	0.0404	0.0627	0.0345	0.0410	0.0393	0.0406
.	.	.	.	.	.	.
A645	0.0389	0.0342	0.0322	0.0391	0.0393	0.0395
A646	0.0386	0.0334	0.0336	0.0391	0.0393	0.0392
A647	0.0390	0.0306	0.0367	0.0363	0.0358	0.0361
A648	0.0388	0.0282	0.0367	0.0354	0.0354	0.0355
A649	0.0390	0.0318	0.0358	0.0391	0.0388	0.0391

Table 5.1.2.3 Weights of each criterion evaluated in DEMATEL method

Weights	**Value**
w_1	0.25
w_2	0.06
w_3	0.01
w_4	0.23
w_5	0.24
w_6	0.21

Table 5.1.2.4 Weighted normalized decision matrix of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
A1	0.00924	0.00170	0.00040	0.00857	0.00944	0.00790
A2	0.00963	0.00223	0.00040	0.00986	0.01043	0.00907
A3	0.00939	0.00192	0.00042	0.00943	0.01020	0.00866
A4	0.00966	0.00202	0.00041	0.00943	0.00990	0.00866
A5	0.00971	0.00193	0.00043	0.00921	0.00955	0.00839
.	.	.	.	.	.	.
A256	0.00962	0.00174	0.00036	0.01222	0.01381	0.01110
.	.	.	.	.	.	.
A366	0.00932	0.00160	0.00038	0.00771	0.00814	0.00700
.	.	.	.	.	.	.
A470	0.01042	0.00180	0.00043	0.00900	0.00872	0.00822
.	.	.	.	.	.	.
A617	0.01010	0.00376	0.00035	0.00943	0.00942	0.00854
.	.	.	.	.	.	.
A645	0.00973	0.00205	0.00032	0.00900	0.00944	0.00829
A646	0.00965	0.00200	0.00034	0.00900	0.00944	0.00824
A647	0.00976	0.00183	0.00037	0.00836	0.00859	0.00758
A648	0.00971	0.00170	0.00037	0.00814	0.00850	0.00746
A649	0.00975	0.00191	0.00036	0.00900	0.00931	0.00822

Table 5.1.2.5 Calculation of positive and negative ideal solution of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

	C1	C2	C3	C4	C5	C6
A^+	0.010568	0.003760	0.00546	0.012215	0.013811	0.011104
A^-	0.009018	0.001587	0.00027	0.007500	0.007693	0.006897

Table 5.1.2.6 The distance of each alternative to the positive ideal solution of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
A1	0.000002	0.000004	0.000000	0.000013	0.000019	0.000010	0.006978
A2	0.000001	0.000002	0.000000	0.000006	0.000011	0.000004	0.004931
A3	0.000001	0.000003	0.000000	0.000008	0.000013	0.000006	0.005618
A4	0.000001	0.000003	0.000000	0.000008	0.000015	0.000006	0.005735
A5	0.000001	0.000003	0.000000	0.000009	0.000018	0.000007	0.006217
.	.	.	.	.	.	.	.
A256	0.000001	0.000004	0.000000	0.000000	0.000000	0.000000	0.002240
.	.	.	.	.	.	.	.
A366	0.000002	0.000005	0.000000	0.000020	0.000032	0.000017	0.008694
.	.	.	.	.	.	.	.
A470	0.000000	0.000004	0.000000	0.000010	0.000026	0.000008	0.006960
.	.	.	.	.	.	.	.
A617	0.000000	0.000000	0.000000	0.000008	0.000019	0.000007	0.005819
.	.	.	.	.	.	.	.
A645	0.000001	0.000003	0.000000	0.000010	0.000019	0.000008	0.006409
A646	0.000001	0.000003	0.000000	0.000010	0.000019	0.000008	0.006453
A647	0.000001	0.000004	0.000000	0.000015	0.000027	0.000012	0.007680
A648	0.000001	0.000004	0.000000	0.000017	0.000028	0.000013	0.007944
A649	0.000001	0.000003	0.000000	0.000010	0.000020	0.000008	0.006565

Table 5.1.2.7 The distance of each alternative to the negative ideal solution of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
A1	0.000000	0.000000	0.000000	0.000001	0.000003	0.000001	0.002298
A2	0.000000	0.000000	0.000000	0.000006	0.000008	0.000005	0.004315
A3	0.000000	0.000000	0.000000	0.000004	0.000006	0.000003	0.003657
A4	0.000000	0.000000	0.000000	0.000004	0.000005	0.000003	0.003511
A5	0.000000	0.000000	0.000000	0.000003	0.000003	0.000002	0.003038
.	.	.	.	.	.	.	.
A256	0.000000	0.000000	0.000000	0.000022	0.000037	0.000018	0.008817
.	.	.	.	.	.	.	.
A366	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000596
.	.	.	.	.	.	.	.
A470	0.000002	0.000000	0.000000	0.000002	0.000001	0.000002	0.002660
.	.	.	.	.	.	.	.
A617	0.000001	0.000005	0.000000	0.000004	0.000003	0.000003	0.003911
.	.	.	.	.	.	.	.
A645	0.000001	0.000000	0.000000	0.000002	0.000003	0.000002	0.002821
A646	0.000000	0.000000	0.000000	0.000002	0.000003	0.000002	0.002770
A647	0.000001	0.000000	0.000000	0.000001	0.000001	0.000000	0.001619
A648	0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	0.001371
A649	0.000001	0.000000	0.000000	0.000002	0.000003	0.000002	0.002690

Table 5.1.2.8 Calculation of relative proximity of TOPSIS application for 800 DEN ATY samples with DEMATEL weights

Alternatives	S_i^-	S_i^*	C_i^*
A1	0.002298	0.006978	0.247772
A2	0.004315	0.004931	0.466725
A3	0.003657	0.005618	0.394277
A4	0.003511	0.005735	0.379713
A5	0.003038	0.006217	0.328246
.	.	.	.
A256	0.008817	0.002240	0.797436
.	.	.	.
A366	0.000596	0.008694	0.064164
.	.	.	.
A470	0.002660	0.006960	0.276499
.	.	.	.
A617	0.003911	0.005819	0.401946
.	.	.	.
A645	0.002821	0.006409	0.305637
A646	0.002770	0.006453	0.300328
A647	0.001619	0.007680	0.174075
A648	0.001371	0.007944	0.147188
A649	0.002690	0.006565	0.290680

Table 5.1.2.9 Ranking of 800 DEN ATY samples with TOPSIS method and DEMATEL weights

Ranking	Alternative	C_i^*
Best alternative	A256	0.797436
Worst Alternative	A366	0.064164

As a result of TOPSIS application of 800 DEN ATY with DEMATEL weights, it can be clearly seen that, the best alternative has the closest values to the quality standards. Therefore ranking of ATY samples and identification of the best and worst alternative were also approved from the company.

5.2 Scenario Analysis

There are two parts in the scope of Scenario Analysis section. Once TOPSIS method is applied again with the equal weights of each criterion, then a quality classification model is proposed with FIS.

5.2.1 TOPSIS method for 800 DEN ATY samples with equal weights

Since ranking ATY samples with the weights evaluated in DEMATEL method, TOPSIS method is developed again with the equal weights of criteria to compare the results. From Table 5.2.1.1 to 5.2.1.9 respectively represents the TOPSIS application developed for 800 DEN ATY samples with equal weights. It can be understood from Table 5.2.1.9 results are changed that the best alternative is now A304 and the worst alternative is now A561.

Table 5.2.1.1 Decision matrix of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
A1	787	11.00	8.90	4.00	36.52	3.23
A2	820	14.50	8.80	4.60	40.37	3.71
A3	800	12.50	9.50	4.40	39.45	3.54
A4	823	13.10	9.10	4.40	38.31	3.54
A5	827	12.50	9.70	4.30	36.94	3.43
.	.	.	.	.	.	.
A304	802	10.60	8.20	3.70	32.63	2.94
.	.	.	.	.	.	.
A561	892	24.20	9.40	4.40	34.98	3.50
.	.	.	.	.	.	.
A645	829	13.30	7.20	4.20	36.50	3.39
A646	822	13.00	7.50	4.20	36.50	3.37
A647	831	11.90	8.20	3.90	33.22	3.10
A648	827	11.00	8.20	3.80	32.88	3.05
A649	830	12.40	8.00	4.20	36.00	3.36

Table 5.2.1.2 Normalized decision matrix of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
A1	0.0370	0.0282	0.0398	0.0373	0.0393	0.0376
A2	0.0385	0.0372	0.0394	0.0429	0.0435	0.0432
A3	0.0376	0.0321	0.0425	0.0410	0.0425	0.0412
A4	0,0387	0.0336	0.0407	0.0410	0.0413	0.0412
A5	0,0388	0.0321	0.0434	0.0401	0.0398	0.0399
.	.	.	.	.	.	.
A304	0.0377	0.0272	0.0367	0.0345	0.0351	0.0342
.	.	.	.	.	.	.
A561	0.0419	0.0621	0.0421	0.0410	0.0377	0.0408
.	.	.	.	.	.	.
A645	0.0389	0.0342	0.0322	0.0391	0.0393	0.0395
A646	0.0386	0.0334	0.0336	0.0391	0.0393	0.0392
A647	0.0390	0.0306	0.0367	0.0363	0.0358	0.0361
A648	0.0388	0.0282	0.0367	0.0354	0.0354	0.0355
A649	0.0390	0.0318	0.0358	0.0391	0.0388	0.0391

Table 5.2.1.3 Weights of each criterion of TOPSIS application for 800 DEN ATY samples (with equal weights)

Weights	**Value**
w_1	0.166
w_2	0.166
w_3	0.166
w_4	0.166
w_5	0.166
w_6	0.166

Table 5.2.1.4 Weighted normalized decision matrix of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
A1	0.006136	0.004689	0.006610	0.006186	0.006529	0.006245
A2	0.006393	0.006181	0.006536	0.007114	0.007218	0.007173
A3	0.006237	0.005329	0.007056	0.006805	0.007053	0.006844
A4	0.006417	0.005584	0.006759	0.006805	0.006849	0.006844
A5	0.006448	0.005329	0.007204	0.006650	0.006604	0.006632
.	.	.	.	.	.	.
A304	0.006253	0.004519	0.006090	0.005722	0.005834	0.005684
.	.	.	.	.	.	.
A561	0.006955	0.010316	0.006982	0.006805	0.006254	0.006767
.	.	.	.	.	.	.
A645	0.006463	0.005670	0.005348	0.006496	0.006526	0.006554
A646	0.006409	0.005542	0.005570	0.006496	0.006526	0.006515
A647	0.006479	0.005073	0.006090	0.006032	0.005939	0.005993
A648	0.006448	0.004689	0.006090	0.005877	0.005878	0.005897
A649	0.006471	0.005286	0.005942	0.006496	0.006436	0.006496

Table 5.2.1.5 Calculation of positive and negative ideal solution of TOPSIS application for 800 DEN ATY samples with equal weights

	C1	C2	C3	C4	C5	C6
A^+	0.0063	0.0424	0.0136	0.0133	0.0058	0.0053
A^-	0.0054	0.0040	0.0068	0.0082	0.0032	0.0033

Table 5.2.1.6 The distance of each alternative to the positive ideal solution of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
A1	0.000001	0.000033	0.000006	0.000007	0.000009	0.000006	0.007866
A2	0.000000	0.000018	0.000006	0.000003	0.000005	0.000003	0.005958
A3	0.000001	0.000026	0.000004	0.000004	0.000006	0.000004	0.006662
A4	0.000000	0.000023	0.000005	0.000004	0.000007	0.000004	0.006629
A5	0.000000	0.000026	0.000003	0.000005	0.000009	0.000005	0.006891
.	.	.	.	.	.	.	.
A304	0.000001	0.000035	0.000009	0.000010	0.000014	0.000010	0.008774
.	.	.	.	.	.	.	.
A561	0.000000	0.000000	0.000004	0.000004	0.000011	0.000004	0.004827
.	.	.	.	.	.	.	.
A645	0.000000	0.000022	0.000014	0.000005	0.000009	0.000005	0.007481
A646	0.000000	0.000024	0.000012	0.000005	0.000009	0.000005	0.007472
A647	0.000000	0.000028	0.000009	0.000008	0.000013	0.000008	0.008128
A648	0.000000	0.000033	0.000009	0.000009	0.000013	0.000008	0.008498
A649	0.000000	0.000026	0.000010	0.000005	0.000010	0.000005	0.007516

Table 5.2.1.7 The distance of each alternative to the negative ideal solution of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
A1	0.000000	0.000000	0.000004	0.000001	0.000001	0.000001	0.002668
A2	0.000000	0.000003	0.000004	0.000003	0.000004	0.000003	0.004104
A3	0.000000	0.000001	0.000006	0.000002	0.000003	0.000002	0.003767
A4	0.000000	0.000001	0.000005	0.000002	0.000002	0.000002	0.003575
A5	0.000000	0.000001	0.000007	0.000002	0.000002	0.000001	0.003579
.	.	.	.	.	.	.	.
A304	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000	0.001712
.	.	.	.	.	.	.	.
A561	0.000001	0.000035	0.000006	0.000002	0.000001	0.000002	0.006825
.	.	.	.	.	.	.	.
A645	0.000000	0.000002	0.000001	0.000001	0.000001	0.000001	0.002523
A646	0.000000	0.000001	0.000001	0.000001	0.000001	0.000001	0.002517
A647	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000	0.002048
A648	0.000000	0.000000	0.000002	0.000000	0.000000	0.000000	0.001859
A649	0.000000	0.000001	0.000002	0.000001	0.000001	0.000001	0.002556

Table 5.2.1.8 Calculation of relative proximity of TOPSIS application for 800 DEN ATY samples with equal weights

Alternatives	S_i^-	S_i^*	C_i^*
A1	0.002668	0.007866	0.253300
A2	0.004104	0.005958	0.407876
A3	0.003767	0.006662	0.361208
A4	0.003575	0.006629	0.350352
A5	0.003579	0.006891	0.341810
.	.	.	.
A304	0.001712	0.008774	0.163256
.	.	.	.
A561	0.006825	0.004827	0.585737
.	.	.	.
A645	0.002523	0.007481	0.252198
A646	0.002517	0.007472	0.251995
A647	0.002048	0.008128	0.201286
A648	0.001859	0.008498	0.179496
A649	0.002556	0.007516	0.253744

Table 5.2.1.9 Ranking of 800 DEN ATY samples with TOPSIS method and equal weights

Ranking	Alternative	C_i^*
Best alternative	A304	0.163256
Worst Alternative	A561	0.585737

5.2.2 Quality classification model for 800 DEN ATY samples

In the textile mill, all yarns that are ready for sale are sold at the same price. As an example a yarn group which has very good values according to quality standards and a yarn group with average values are priced at the same selling price. Also faulty yarns are not often realized before they reach the customer. A quality classification model is developed to avoid yarn defects before they reach the customer and to determine a price strategy based on quality. A fuzzy inference system is evaluated for quality classification model to deal with uncertainty due to linguistic variables occur while interpreting quality of the yarn.

The six physical properties of ATY (count, tenacity, elongation, shrinkage, breaking force, RKM) are used as the input parameters of FIS model evaluated. Figure 5.2.2.1 represents the flow chart of proposed model. A MATLAB based coding is developed to execute the proposed fuzzy model of '*quality classification*'. Figure 5.2.2.2 shows the main stucture of the model evaluated.

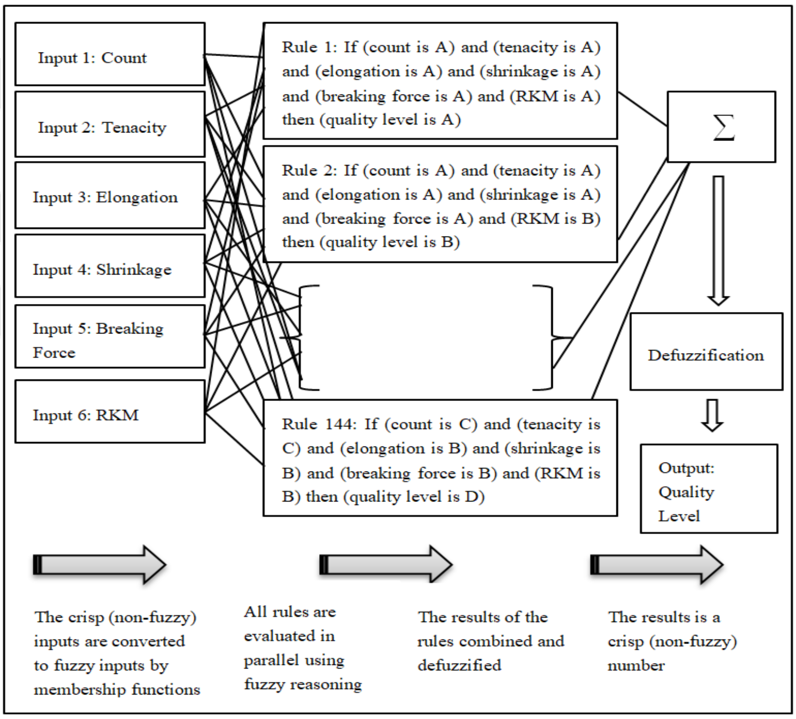

Figure 5.2.2.1 Flow chart of proposed model

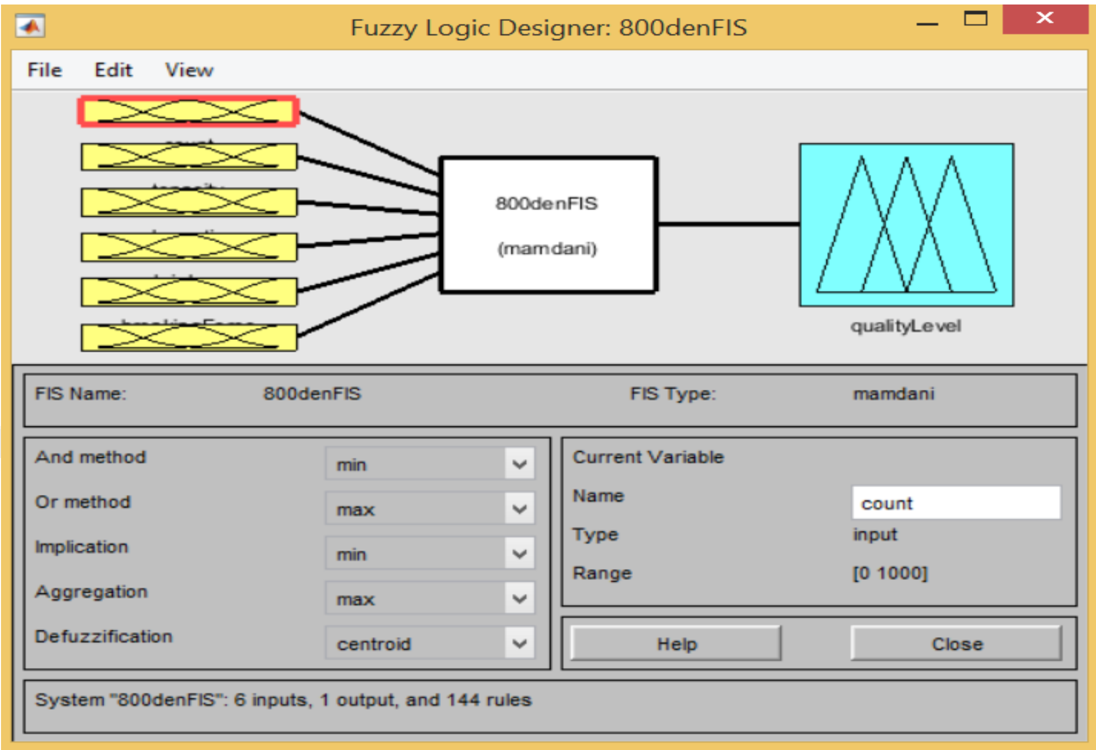

Figure 5.2.2.2 MATLAB Fuzzy Logic Toolbox

There are three linguistic fuzzy sets namely best (A), average(B), non-acceptable (C), generated for input parameters of '*Count*' and '*Tenacity*'. Two linguistic fuzzy sets, namely acceptable (A) and non-acceptable (B) are generated for input parameters of '*Elongation*', '*Shrinkage*', '*Breaking force*' and '*RKM*'. Three forms of membership functions (triangular, trapezoidal, z-shaped) are used for input parameters of '*Count*' and '*Tenacity*', one form of membership function (trapezoidal) is used for input parameters of '*Elongation*', '*Shrinkage*', '*Breaking force*' and '*RKM*'. Figure 5.2.2.3 represents the membership functions applied for input parameter of '*Count*', Figure 5.2.2.4 represents the membership functions applied for input parameter of '*Tenacity*'. Figure 5.2.2.5, Figure 5.2.2.6, Figure 5.2.2.7, Figure 5.2.2.8 respectively represent the membership functions applied for input parameters of '*Elongation*', '*Shrinkage*', '*Breaking force*' and '*RKM*'.

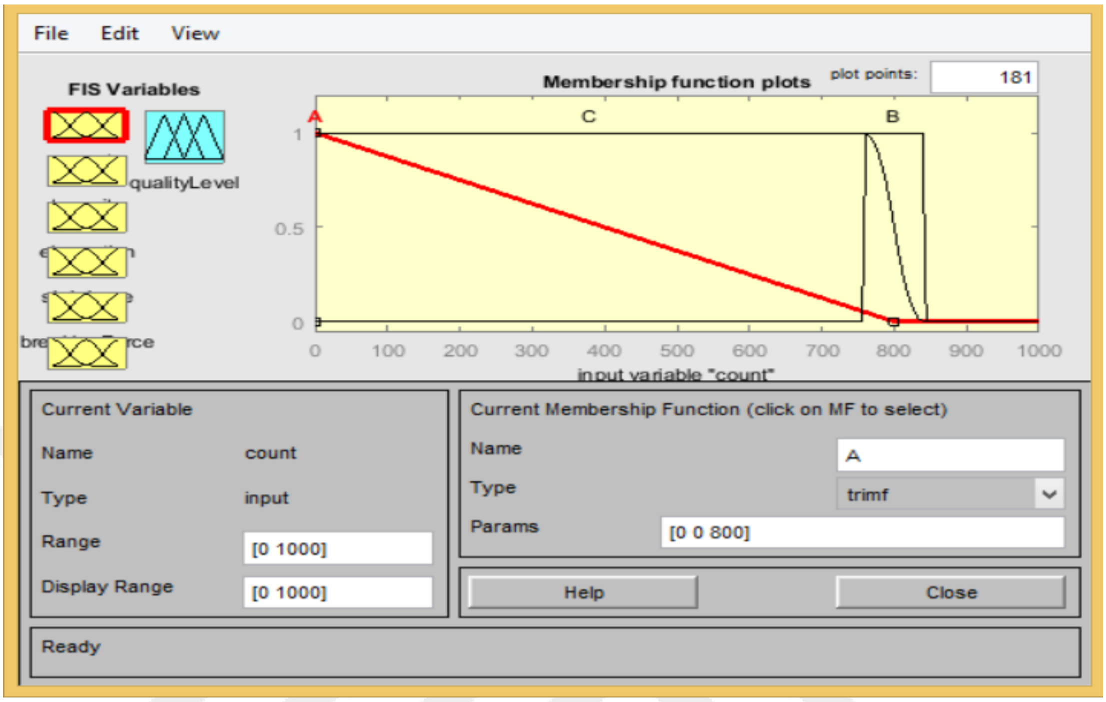

Figure 5.2.2.3 Membership functions of input variable "*Count*"

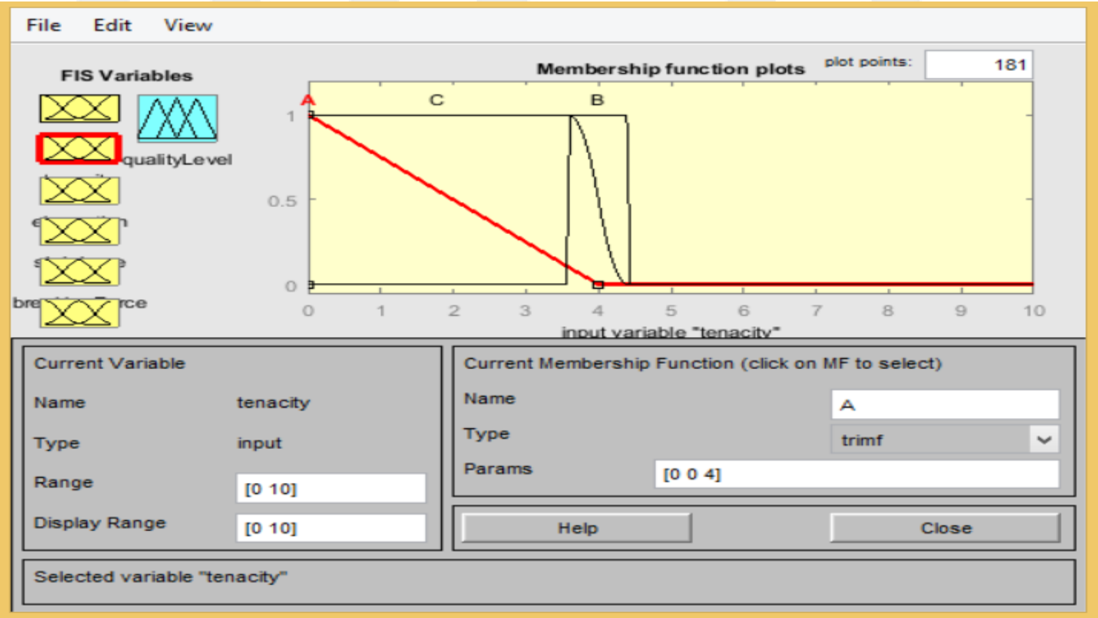

Figure 5.2.2.4 Membership functions of input variable "*Tenacity*"

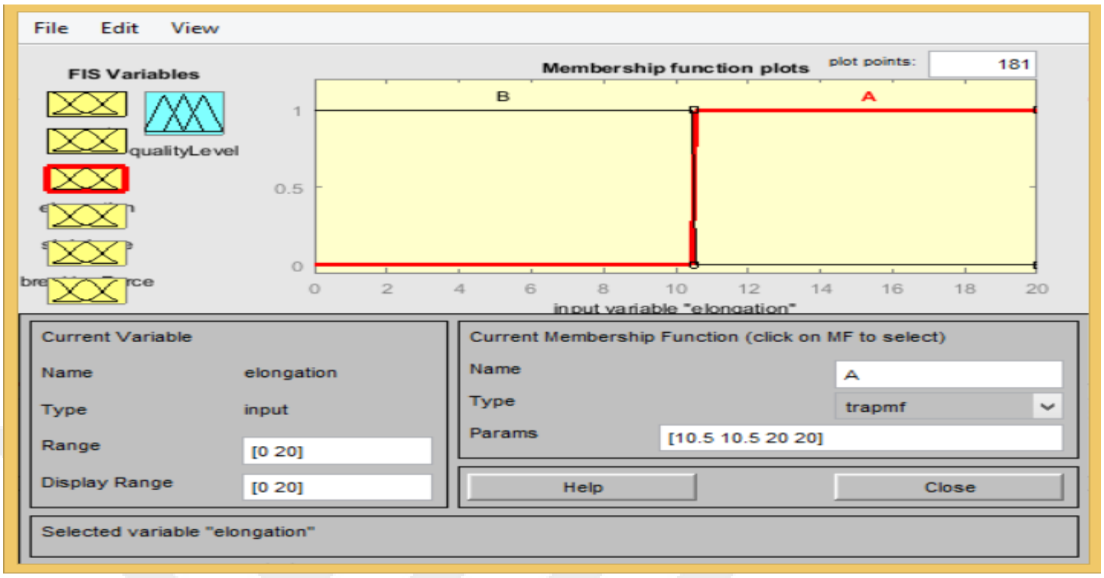

Figure 5.2.2.5 Membership functions of input variable "*Elongation*"

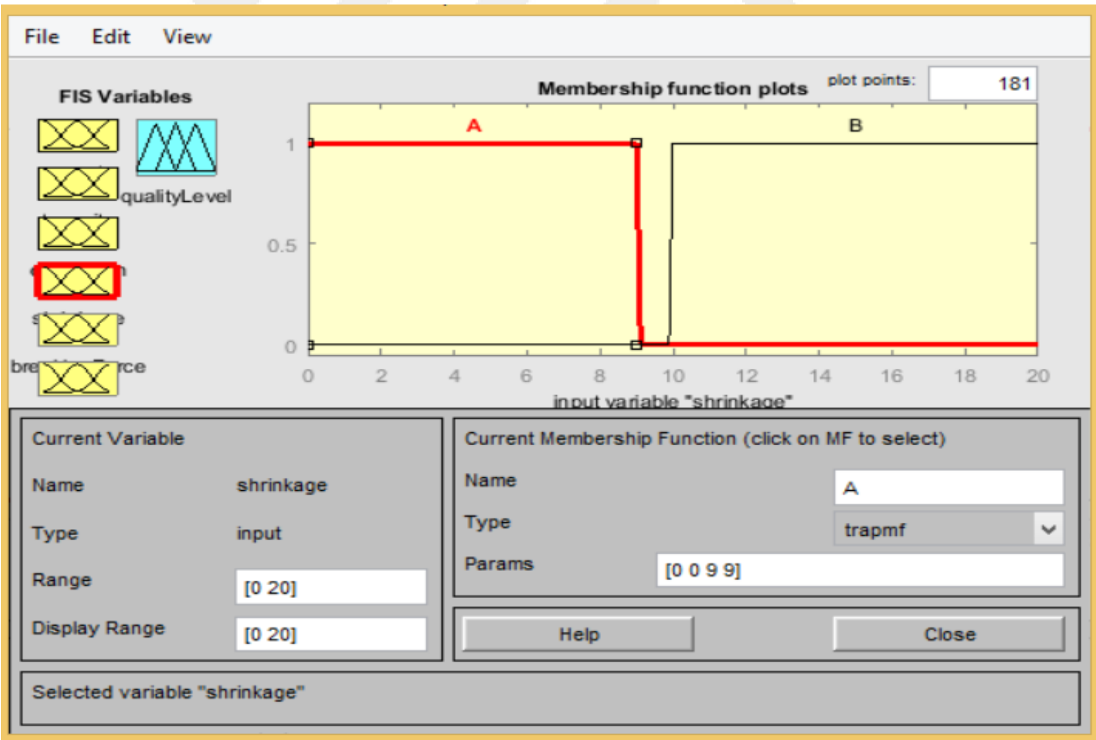

Figure 5.2.2.6 Membership functions of input variable "*Shrinkage*"

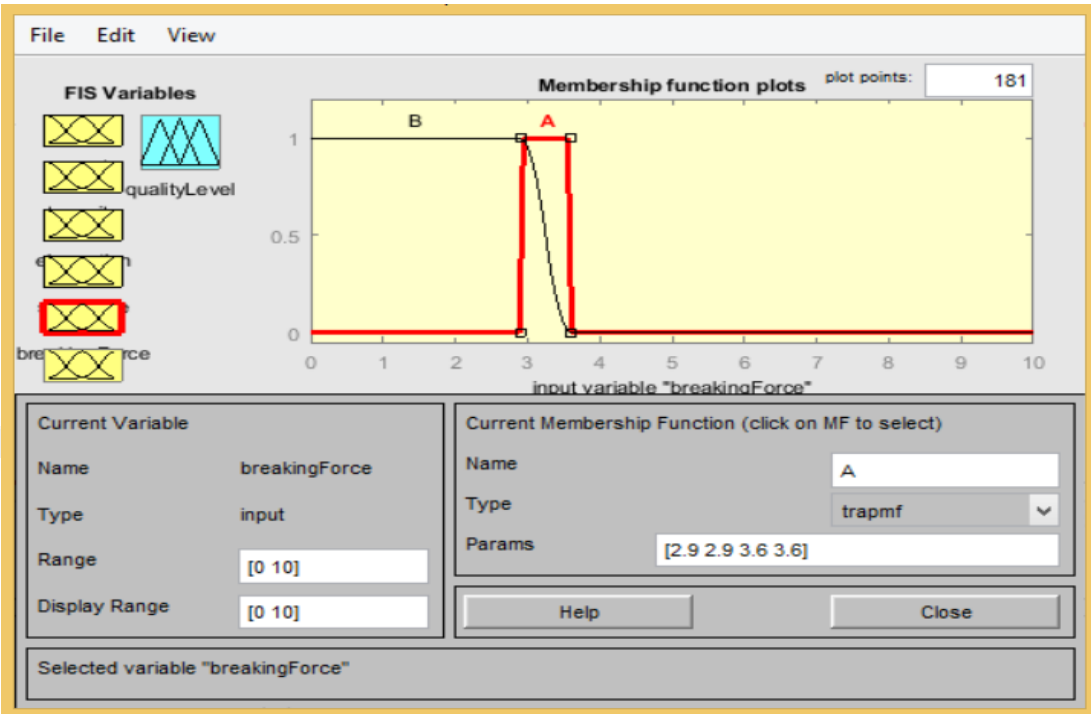

Figure 5.2.2.7 Membership functions of input variable "*Breaking Force*"

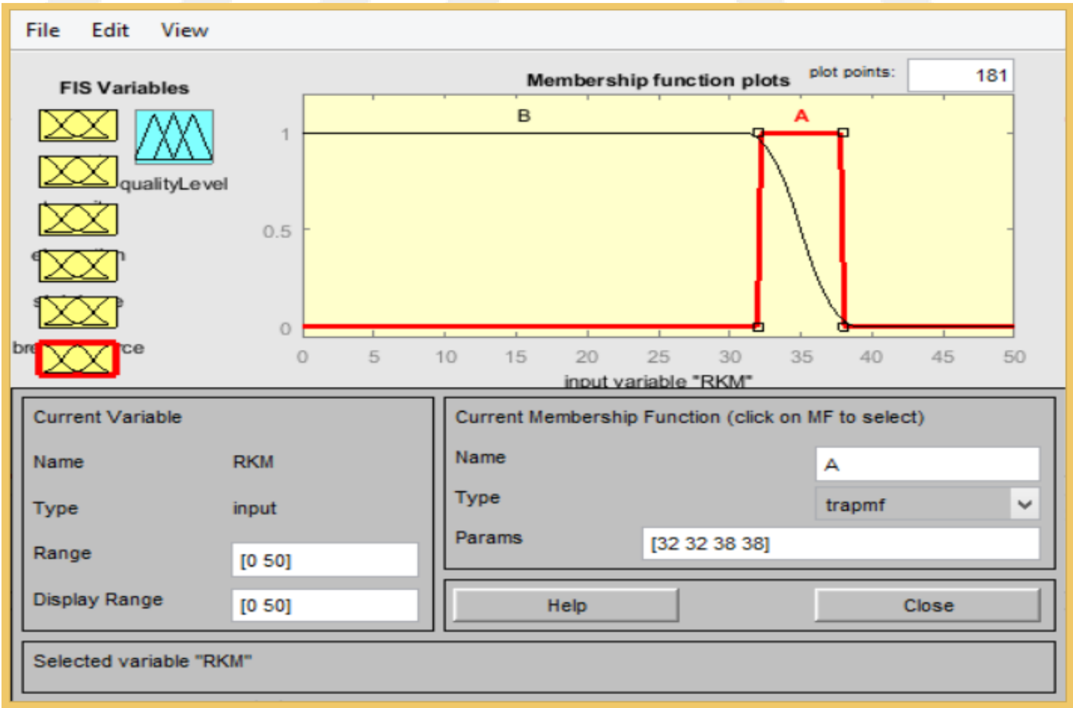

Figure 5.2.2.8 Membership functions of input variable "*RKM*"

Four linguistic fuzzy sets namely best (*A*), average (*B*), low (*C*) and non-acceptable (*D*) are generated for output parameter of '*Quality level*'. One form of membership function (triangular) is used for output parameter. Figure 5.2.2.9 represents the membership function applied for output parameter. Membership functions are developed with Fuzzy Logic Toolbox of MATLAB. The ranges of membership functions for both input and output parameters are compromised according to quality standards values of 800 DEN ATY as shown in Table 5.2.2.1.

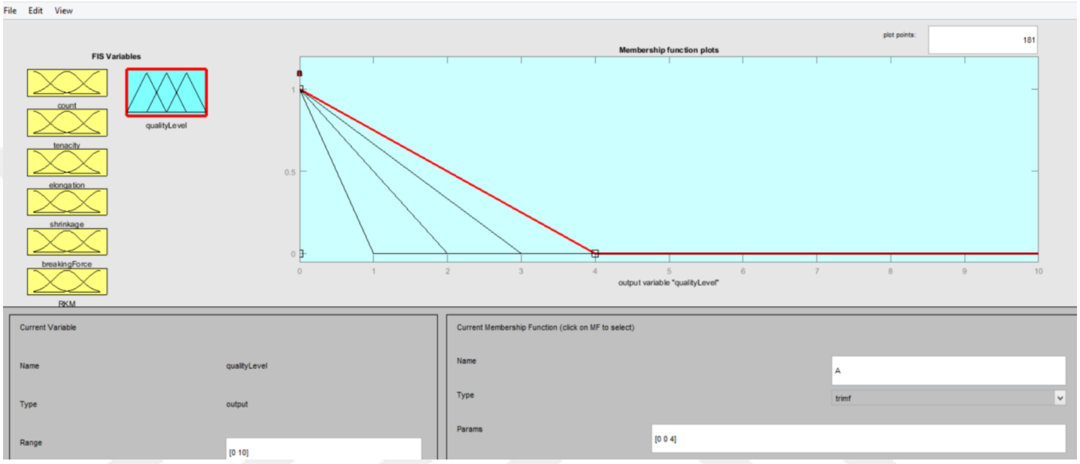

Figure 5.2.2.9 Membership function of output variable "*Quality Level*"

Table 5.2.2.1 Quality standards of 800 DEN ATY

Ranking	Range
Count	800 +- %5
Tenacity	4 +- %10
Elongation	>= 10.50
Shrinkage	< 10.00
Breaking force	2.90 <= breaking force <= 33.60
RKM	32.00 <= RKM <= 38.00

Following fuzzification, total 144 rules are created for the output and input variables with the help of expert knowledge and previous experience of the quality control manager of the firm. As an example of rule base if (*count* is *A*) and (if *tenacity* is *A*) and (*elongation* is *A*) and (*shrinkage* is *A*) and (*breaking force* is *A*) and (*RKM* is *B*) then (*quality level* is *B*). Table 5.2.2.2 shows a brief view of rules added to FIS to create a proportional control surface. A Mamdani max-min inference approach is applied for combination of fuzzy sets into a single fuzzy set. Finally centroid defuzzification method is used to convert the output into non-fuzzy crisp numeric value. Figure 5.2.2.10 shows the rule viewer of FIS. The rule viewer is the interface that shows the change in output parameter as a result of changes in input parameters. The decision makers can take the final decision by this interface to select optimum input parameters.

Table 5.2.2.2 The rule base of the Quality Classification model

	IF	THEN
1	The Count is A, the tenacity is A, the elongation is A, the shrinkage is A ,the breaking force is A and the RKM is A	The quality level is A
2	The Count is A, the tenacity is A, the elongation is A, the shrinkage is A, the breaking force is A and the RKM is B	The quality level is B
3	The Count is A, the tenacity is A, the elongation is A, the shrinkage is A, the breaking force is B and the RKM is A	The quality level is B
	.	.
50	The Count is B, the tenacity is A, the elongation is A, the shrinkage is A, the breaking force is A and the RKM is B	The quality level is C
.	.	.
58	The Count is B, the tenacity is A, the elongation is B, the shrinkage is A, the breaking force is A and the RKM is B	The quality level is D
.	.	.
144	The Count is C, the tenacity is C, the elongation is B, the shrinkage is B, the breaking force is B and the RKM is B	The quality level is D

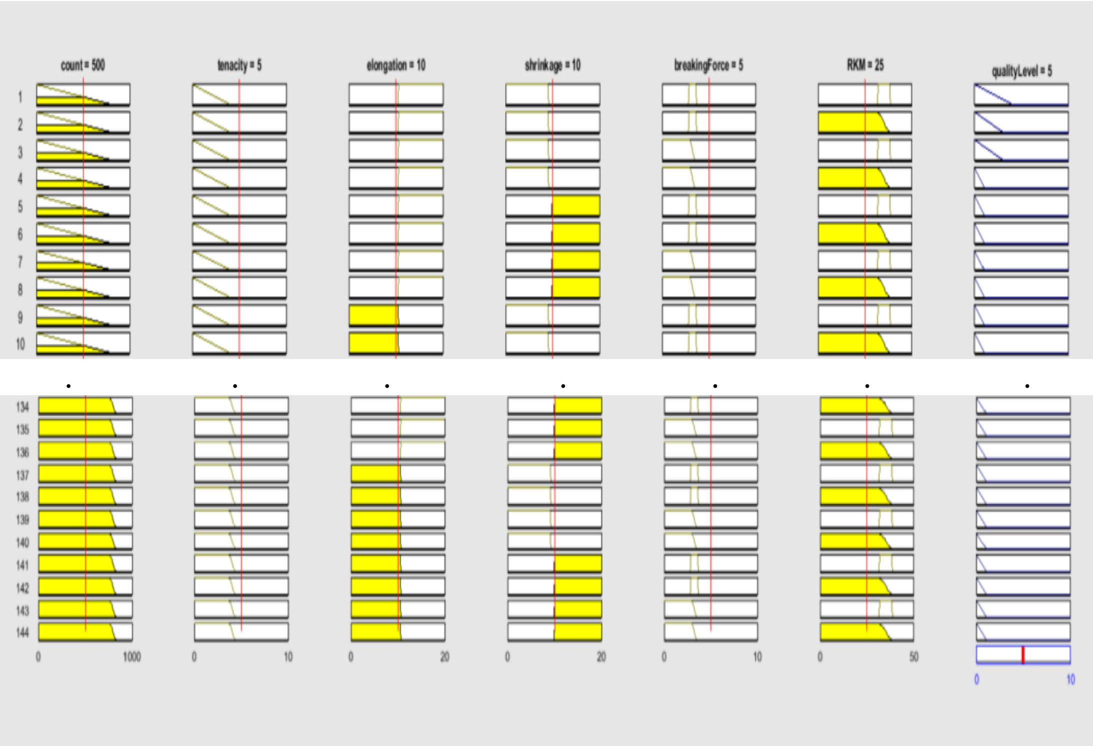

Figure 5.2.2.10 MATLAB Rule Viewer

CHAPTER VI

CONCLUSION

Quality has become the most important an important issue in textile industry, as many other manufacturing industries. Rapidly increasing technological developments over the years and increased trade around the world have caused significantly increasing competition in textile sector. Therefore in the textile sector where competition is high, companies have sought the production of quality products with high prefer ability.

Air textured yarn is used as warp yarn by carpet manufacturers and the quality of ATY directly affects the quality of the carpet to be produced. Therefore, companies producing this type of yarn should adopt a production system based on the philosophy of producing high quality products.

In this thesis, the study covers an extent research on a company aiming at a standard in quality and producing air textured warp yarn. The samples of ATY are randomly selected from production line and subjected to strength tests after the production process. After all test procedures are completed physical properties of yarn are identified with test values of the yarn.

In order to determine the yarn sample with best value and comparing test values of the yarn with quality standard, making a quality classification about ATY, can be a multi-criteria decision-making problem. One of the aims of this thesis is to help decision makers with taking more scientifically and technical decisions to solve this decision making problem. In order to do this, this thesis focuses on *MCDM Methods*. As MCDM methods, DEMATEL method is used to determine weights of criteria, TOPSIS is used to determine the yarn which has the best value and rank yarn samples from best to worst.

In the Methods section of the thesis for MCDM methods, data set is generated by concentrating on the six months production period reports of quality control department of the firm, with four types of products which are 800 DEN ATY, 1100 DEN ATY, 1350 DEN ATY and 1600 DEN ATY. MCDM techniques are applied for 800 DEN ATY and for other types of products (1100 DEN, 1350 DEN and 1600

DEN ATY) the applications of MCDM techniques are available in Appendix section. Physical properties of the yarn are used as criteria for both DEMATEL and TOPSIS method, and yarn samples are used as alternatives for the methods.

DEMATEL method is consulted to define the interaction between the criteria and determine the weights of the criteria. As a result of DEMATEL method, *Count* is the criteria maximally influence remaining properties (*Elongation*, *Shrinkage*, *Tenacity*, *RKM* and *Breaking Force*). Since analyze the weights of the six criteria with DEMATEL method, TOPSIS method is evaluated to rank yarn samples and make a comparison between the test results of the yarn and quality standards. Ranking all samples from best to worst will provide to make a classification about quality level of the yarn. As a result of TOPSIS application with DEMATEL weights, Alternative 256 (A256) is the best yarn sample which is the most close to the standard quality values and can be marked at the highest level of the quality classification. Alternative 366 (A366) is the worst yarn sample and can be marked at the lowest level of the quality classification.

As the scope of Scenario Analysis section TOPSIS is evaluated again with equal weights of criteria. The results are changed. As a result of TOPSIS application with equal weights Alternative 304 (A304) is the best yarn sample and can be marked at the highest level of the quality classification, Alternative 561 (A561) is the worst yarn sample and can be marked at the lowest level of the quality classification. A comparison can be done between the any samples with standard quality values, according the ranking. Managers of the firm can also define a pricing strategy with the help of the quality classification. Yarns at the highest level of the classification can be assigned as high-cost merchandise and that can be more profitable for the firm. Ranking also is useful to eliminate yarn faults at the quality control process before meet the customer.

In the second part of Scenario Analysis section, a fuzzy quality classification model is proposed with using FIS. The developed fuzzy rules give a very good understanding about the interaction between the factors. Different membership functions are used for input parameters and one form membership function is used for output parameter. The ranges of membership functions are compromised according the quality standards of the yarn. The Mamdani inference engine is used for the model. As a result of the model, it is seen that two of yarn samples are at the best level (A), 382 of yarn samples are at the average level (B), 54 of yarn samples are at the low level (C), 225 of yarn samples are at the non-acceptable level of quality classification. To conclude, the quality level of any yarn sample can be identified with the model. A quality classification model can help the company to estimate the yarn on which level is it. Therefore yarn faults can be eliminated before they reach the customer. Also a better pricing strategy can be done with the help of the quality classification model. The system is quite easy to develop and it can be modified easily any type of product which has any different denier. Further attempts are implementing this model to yarns which has got different denier and quality standard values. Recommendations for future studies are evaluating the model with Sugeno inference engine to compare the results and developing a decision support system for the company.

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APPENDIX

Table A.1 Decision matrix of TOPSIS application for 1100 DEN ATY samples with DEMATEL weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1083	13.00	8.00	4.20	38.27	4.65
Alt2	1079	13.00	8.10	4.10	37.43	4.53
Alt3	1091	12.50	7.50	4.10	36.56	4.48
Alt4	1078	12.30	7.80	4.10	36.87	4.46
Alt5	1089	13.20	7.60	4.10	37.14	4.54
Alt6	1092	13.10	7.50	4.30	38.84	4.70
.	.	.	.	.	.	.
Alt65	1078	11.50	8.10	3.40	30.59	3.76
.	.	.	.	.	.	.
Alt122	1095	15.40	7.40	4.20	37.98	4.67
.	.	.	.	.	.	.
Alt616	1104	11.40	6.70	3.60	31.63	3.92
.	.	.	.	.	.	.
Alt625	1110	12.40	7.10	3.80	33.75	4.16
Alt626	1109	13.00	6.80	3.70	33.14	4.12
Alt627	1100	12.70	6.80	3.80	33.95	4.19
Alt628	1100	12.30	6.20	3.80	34.31	4.21
Alt629	1101	13.50	6.90	3.90	34.54	4.27

Table A.2 Normalized decision matrix of TOPSIS application for 1100 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0390	0.0366	0.0410	0.0432	0.0444	0.0435
Alt2	0.0389	0.0366	0.0415	0.0422	0.0434	0.0423
Alt3	0.0393	0.0351	0.0384	0.0422	0.0424	0.0419
Alt4	0.0389	0.0346	0.0400	0.0422	0.0428	0.0417
Alt5	0.0393	0.0371	0.0389	0.0422	0.0431	0.0424
Alt6	0.0394	0.0368	0.0384	0.0442	0.0451	0.0439
.	.	.	.	.	.	.
Alt65	0.0389	0.0323	0.0415	0.0350	0.0355	0.0351
.	.	.	.	.	.	.
Alt122	0.0395	0.0433	0.0379	0.0432	0.0441	0.0437
.	.	.	.	.	.	.
Alt616	0.0398	0.0321	0.0343	0.0370	0.0367	0.0366
.	.	.	.	.	.	.
Alt625	0.0400	0.0349	0.0364	0.0391	0.0392	0.0389
Alt626	0.0400	0.0366	0.0348	0.0381	0.0385	0.0385
Alt627	0.0397	0.0357	0.0348	0.0391	0.0394	0.0392
Alt628	0.0397	0.0346	0.0318	0.0391	0.0398	0.0394
Alt629	0.0397	0.0380	0.0354	0.0401	0.0401	0.0399

Table A.3 Weights of each criterion of TOPSIS application for 1100 DEN ATY samples (with DEMATEL weights)

Weights	**Value**
w_1	0.25
w_2	0.06
w_3	0.01
w_4	0.23
w_5	0.24
w_6	0.21

Table A.4 Weighted normalized decision matrix solution of TOPSIS application for 1100 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.009760	0.002193	0.000410	0.009937	0.010659	0.009128
Alt2	0.009724	0.002193	0.000415	0.009701	0.010425	0.008892
Alt3	0.009832	0.002109	0.000384	0.009701	0.010183	0.008794
Alt4	0.009715	0.002075	0.000400	0.009701	0.010269	0.008755
Alt5	0.009814	0.002227	0.000389	0.009701	0.010344	0.008912
Alt6	0.009841	0.002210	0.000384	0.010174	0.010818	0.009226
.	.	.	.	.	.	.
Alt65	0.009715	0.001940	0.000415	0.008045	0.008520	0.007381
.	.	.	.	.	.	.
Alt122	0.009868	0.002598	0.000379	0.009937	0.010578	0.009167
.	.	.	.	.	.	.
Alt616	0.009949	0.001923	0.000343	0.008518	0.008810	0.007695
.	.	.	.	.	.	.
Alt625	0.010003	0.002092	0.000364	0.008991	0.009400	0.008166
Alt626	0.009994	0.002193	0.000348	0.008754	0.009230	0.008087
Alt627	0.009913	0.002142	0.000348	0.008991	0.009456	0.008225
Alt628	0.009913	0.002075	0.000318	0.008991	0.009556	0.008264
Alt629	0.009922	0.002277	0.000354	0.009228	0.009620	0.008382

Table A.5 Calculation of positive and negative ideal solution of TOPSIS application for 1100 DEN ATY Samples with DEMATEL weights

	C1	C2	C3	C4	C5	C6
A^+	0.0104	0.0026	0.0005	0.0104	0.0108	0.0106
A^-	0.0094	0.0018	0.0003	0.0076	0.0078	0.0074

Table A.6 The distance of each alternative to the positive ideal solution of TOPSIS application for 1100 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000000	0.000396	0.000000	0.000000	0.000000	0.000002	0.019979
Alt2	0.000000	0.000396	0.000000	0.000001	0.000000	0.000003	0.020009
Alt3	0.000000	0.000400	0.000000	0.000001	0.000000	0.000003	0.020105
Alt4	0.000000	0.000401	0.000000	0.000001	0.000000	0.000004	0.020143
Alt5	0.000000	0.000395	0.000000	0.000001	0.000000	0.000003	0.019973
Alt6	0.000000	0.000396	0.000000	0.000000	0.000000	0.000002	0.019948
.	.	.	.	.	.	.	.
Alt65	0.000000	0.000407	0.000000	0.000002	0.000001	0.000006	0.020411
.	.	.	.	.	.	.	.
Alt122	0.000000	0.000380	0.000000	0.000000	0.000000	0.000002	0.019570
.	.	.	.	.	.	.	.
Alt616	0.000000	0.000407	0.000000	0.000004	0.000004	0.000006	0.020580
.	.	.	.	.	.	.	.
Alt625	0.000000	0.000400	0.000000	0.000002	0.000002	0.000006	0.020263
Alt626	0.000000	0.000396	0.000000	0.000003	0.000003	0.000007	0.020203
Alt627	0.000000	0.000398	0.000000	0.000002	0.000002	0.000006	0.020203
Alt628	0.000000	0.000401	0.000000	0.000002	0.000002	0.000006	0.020259
Alt629	0.000000	0.000393	0.000000	0.000001	0.000001	0.000005	0.020026

Table A.7 The distance of each alternative to the negative ideal solution of TOPSIS application for 1100 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000000	0.000000	0.000000	0.000006	0.000008	0.000003	0.004101
Alt2	0.000000	0.000000	0.000000	0.000005	0.000007	0.000002	0.003702
Alt3	0.000000	0.000000	0.000000	0.000005	0.000005	0.000002	0.003499
Alt4	0.000000	0.000000	0.000000	0.000005	0.000006	0.000002	0.003528
Alt5	0.000000	0.000000	0.000000	0.000005	0.000006	0.000002	0.003666
Alt6	0.000000	0.000000	0.000000	0.000007	0.000009	0.000003	0.004397
.	.	.	.	.	.	.	.
Alt65	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000890
.	.	.	.	.	.	.	.
Alt122	0.000000	0.000001	0.000000	0.000006	0.000007	0.000003	0.004130
.	.	.	.	.	.	.	.
Alt616	0.000000	0.000000	0.000000	0.000001	0.000001	0.000000	0.001490
.	.	.	.	.	.	.	.
Alt625	0.000000	0.000000	0.000000	0.000002	0.000002	0.000001	0.002338
Alt626	0.000000	0.000000	0.000000	0.000001	0.000002	0.000000	0.002071
Alt627	0.000000	0.000000	0.000000	0.000002	0.000003	0.000001	0.002381
Alt628	0.000000	0.000000	0.000000	0.000002	0.000003	0.000001	0.002455
Alt629	0.000000	0.000000	0.000000	0.000003	0.000003	0.000001	0.002712

Table A.8 Calculation of relative proximity of TOPSIS application for 1100 DEN ATY Samples with DEMATEL weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.004101	0.019979	0.170308
Alt2	0.003702	0.020009	0.156123
Alt3	0.003499	0.020105	0.148252
Alt4	0.003528	0.020143	0.149037
Alt5	0.003666	0.019973	0.155085
Alt6	0.004397	0.019948	0.180623
.	.	.	.
Alt65	0.000890	0.020411	0.041252
.	.	.	.
Alt122	0.004130	0.019570	0.174257
.	.	.	.
Alt616	0.001490	0.020580	0.067531
.	.	.	.
Alt625	0.002338	0.020263	0.103461
Alt626	0.002071	0.020203	0.092980
Alt627	0.002381	0.020203	0.105425
Alt628	0.002455	0.019979	0.108099
Alt629	0.002712	0.020009	0.119279

Table A.9 Ranking of 1100 Denier ATY samples with TOPSIS method and DEMATEL weights

Ranking	Alternative	C_i^*
Best alternative	Alt6	0.180623
Worst Alternative	Alt65	0.041252

Table A.10 Decision matrix of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1083	13.00	8.00	4.20	38.27	4.65
Alt2	1079	13.00	8.10	4.10	37.43	4.53
Alt3	1091	12.50	7.50	4.10	36.56	4.48
Alt4	1078	12.30	7.80	4.10	36.87	4.46
Alt5	1089	13.20	7.60	4.10	37.14	4.54
.	.	.	.	.	.	.
Alt122	1095	15.40	7.40	4.20	37.98	4.67
.	.	.	.	.	.	.
Alt616	1104	11.40	6.70	3.60	31.63	3.92
.	.	.	.	.	.	.
Alt625	1110	12.40	7.10	3.80	33.75	4.16
Alt626	1109	13.00	6.80	3.70	33.14	4.12
Alt627	1100	12.70	6.80	3.80	33.95	4.19
Alt628	1100	12.30	6.20	3.80	34.31	4.21
Alt629	1101	13.50	6.90	3.90	34.54	4.27

Table A.11 Normalized decision matrix of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0390	0.0366	0.0410	0.0432	0.0444	0.0435
Alt2	0.0389	0.0366	0.0415	0.0422	0.0434	0.0423
Alt3	0.0393	0.0351	0.0384	0.0422	0.0424	0.0419
Alt4	0,0389	0.0346	0.0400	0.0422	0.0428	0.0417
Alt5	0,0393	0.0371	0.0389	0.0422	0.0431	0.0424
.	.	.	.	.	.	.
Alt122	0.0395	0.0433	0.0379	0.0432	0.0441	0.0437
.	.	.	.	.	.	.
Alt616	0.0398	0.0321	0.0343	0.0370	0.0367	0.0366
.	.	.	.	.	.	.
Alt625	0.0400	0.0349	0.0364	0.0391	0.0392	0.0389
Alt626	0.0400	0.0366	0.0348	0.0381	0.0385	0.0385
Alt627	0.0397	0.0357	0.0348	0.0391	0.0394	0.0392
Alt628	0.0397	0.0346	0.0318	0.0391	0.0398	0.0394
Alt629	0.0397	0.0380	0.0354	0.0401	0.0401	0.0399

Table A.12 Weights of each criterion of TOPSIS application for 1100 DEN ATY samples (with equal weights)

Weights	**Value**
w_1	0.166
w_2	0.166
w_3	0.166
w_4	0.166
w_5	0.166
w_6	0.166

Table A.13 Weighted normalized decision matrix of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.006480	0.006067	0.006805	0.007172	0.007373	0.007215
Alt2	0.006456	0.006067	0.006890	0.007001	0.007211	0.007029
Alt3	0.006528	0.005834	0.006380	0.007001	0.007043	0.006951
Alt4	0.006450	0.005741	0.006635	0.007001	0.007103	0.006920
Alt5	0.006516	0.006161	0.006465	0.007001	0.007155	0.007044
.	.	.	.	.	.	.
Alt122	0.006552	0.007188	0.006295	0.007172	0.007317	0.007246
.	.	.	.	.	.	.
Alt616	0.006606	0.005321	0.005699	0.006148	0.006093	0.006082
.	.	.	.	.	.	.
Alt625	0.006642	0.005787	0.006040	0.006489	0.006502	0.006455
Alt626	0.006636	0.006067	0.005784	0.006318	0.006384	0.006393
Alt627	0.006582	0.005927	0.005784	0.006489	0.006540	0.006501
Alt628	0.006582	0.005741	0.005274	0.006489	0.006610	0.006532
Alt629	0.006588	0.006301	0.005869	0.006660	0.006654	0.006625

Table A.14 Calculation of positive and negative ideal solution of TOPSIS application for 1100 DEN ATY samples with equal weights

	C1	C2	C3	C4	C5	C6
A^+	0.0069	0.0611	0.0077	0.0075	0.0075	0.0084
A^-	0.0063	0.0050	0.0052	0.0055	0.0054	0.0058

Table A.15 The distance of each alternative to the positive ideal solution of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000000	0.003033	0.000001	0.000000	0.000000	0.000001	0.055096
Alt2	0.000000	0.003033	0.000001	0.000000	0.000000	0.000002	0.055101
Alt3	0.000000	0.003059	0.000002	0.000000	0.000000	0.000002	0.055346
Alt4	0.000000	0.003069	0.000001	0.000000	0.000000	0.000002	0.055435
Alt5	0.000000	0.003023	0.000001	0.000000	0.000000	0.000002	0.055015
.	.	.	.	.	.	.	.
Alt122	0.000000	0.002911	0.000002	0.000000	0.000000	0.000001	0.053986
.	.	.	.	.	.	.	.
Alt616	0.000000	0.003116	0.000004	0.000002	0.000002	0.000005	0.055938
.	.	.	.	.	.	.	.
Alt625	0.000000	0.003064	0.000003	0.000001	0.000001	0.000004	0.055430
Alt626	0.000000	0.003033	0.000004	0.000001	0.000001	0.000004	0.055167
Alt627	0.000000	0.003049	0.000004	0.000001	0.000001	0.000004	0.055297
Alt628	0.000000	0.003069	0.000006	0.000001	0.000001	0.000004	0.055500
Alt629	0.000000	0.003007	0.000003	0.000001	0.000001	0.000003	0.054912

Table A.16 The distance of each alternative to the negative ideal solution of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000000	0.000001	0.000003	0.000003	0.000004	0.000002	0.003510
Alt2	0.000000	0.000001	0.000003	0.000002	0.000003	0.000001	0.003310
Alt3	0.000000	0.000001	0.000001	0.000002	0.000003	0.000001	0.002888
Alt4	0.000000	0.000000	0.000002	0.000002	0.000003	0.000001	0.002994
Alt5	0.000000	0.000001	0.000002	0.000002	0.000003	0.000001	0.003124
.	.	.	.	.	.	.	.
Alt122	0.000000	0.000005	0.000001	0.000003	0.000004	0.000002	0.003794
.	.	.	.	.	.	.	.
Alt616	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001199
.	.	.	.	.	.	.	.
Alt625	0.000000	0.000001	0.000001	0.000001	0.000001	0.000000	0.002005
Alt626	0.000000	0.000001	0.000000	0.000001	0.000001	0.000000	0.001874
Alt627	0.000000	0.000001	0.000000	0.000001	0.000001	0.000000	0.001995
Alt628	0.000000	0.000000	0.000000	0.000001	0.000001	0.000000	0.001881
Alt629	0.000000	0.000002	0.000000	0.000001	0.000002	0.000001	0.002392

Table A.17 Calculation of relative proximity of TOPSIS application for 1100 DEN ATY samples with equal weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.003510	0.055096	0.059890
Alt2	0.003310	0.055101	0.056664
Alt3	0.002888	0.055346	0.049593
Alt4	0.002994	0.055435	0.051243
Alt5	0.003124	0.055015	0.053732
.	.	.	.
Alt122	0.003794	0.053986	0.065666
.	.	.	.
Alt616	0.001199	0.055938	0.020978
.	.	.	.
Alt625	0.002005	0.055430	0.034916
Alt626	0.001874	0.055167	0.032856
Alt627	0.001995	0.055297	0.034829
Alt628	0.001881	0.055500	0.032788
Alt629	0.002392	0.054912	0.041741

Table A.18 Ranking of 1100 DEN ATY samples with TOPSIS method and equal weights

Ranking	Alternative	C_i^*
Best alternative	Alt122	0.065666
Worst Alternative	Alt616	0.020978

Table A.19 Decision matrix of TOPSIS application for 1350 DEN ATY samples with DEMATEL weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1340	13.20	8.80	4.80	43.25	6.49
Alt2	1335	13.10	7.50	4.50	40.43	6.13
Alt3	1337	13.20	6.10	4.50	40.29	6.13
Alt4	1339	13.40	6.00	4.50	40.29	6.13
Alt5	1344	13.60	8.90	4.40	38.77	5.95
.	.	.	.	.	.	.
Alt135	1376	15.50	7.60	4.60	42.59	8.43
.	.	.	.	.	.	.
Alt181	1352	12.60	7.50	3.80	33.84	5.13
.	.	.	.	.	.	.
Alt255	1363	13.90	7.70	4.30	37.49	5.74
Alt256	1373	12.40	8.10	4.20	36.46	5.62
Alt257	1376	13.50	7.80	4.20	36.68	5.67
Alt258	1370	13.90	7.30	4.30	37.36	5.74
Alt259	1360	13.10	8.00	4.20	36.87	5.63

Table A.20 Normalized decision matrix of TOPSIS application for 1350 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0483	0.0371	0.0451	0.0494	0.0502	0.0607
Alt2	0.0481	0.0368	0.0384	0.0463	0.0469	0.0573
Alt3	0.0482	0.0371	0.0313	0.0463	0.0468	0.0573
Alt4	0,0483	0.0377	0.0307	0.0463	0.0468	0.0573
Alt5	0,0484	0.0382	0.0456	0.0457	0.0450	0.0556
.	.	.	.	.	.	.
Alt1135	0.0496	0.0436	0.0389	0.0473	0.0494	0.0788
.	.	.	.	.	.	.
Alt181	0.0487	0.0354	0.0384	0.0391	0.0393	0.0480
.	.	.	.	.	.	.
Alt255	0.0491	0.0391	0.0395	0.0442	0.0435	0.0537
Alt256	0.0495	0.0349	0.0415	0.0432	0.0423	0.0525
Alt257	0.0496	0.0380	0.0400	0.0432	0.0426	0.0530
Alt258	0.0494	0.0391	0.0374	0.0442	0.0434	0.0537
Alt259	0.0490	0.0368	0.0410	0.0432	0.0428	0.0526

Table A.21 Weights of each criterion of TOPSIS application for 1350 DEN ATY samples (with DEMATEL weights)

Weights	**Value**
w_1	0.25
w_2	0.06
w_3	0.01
w_4	0.23
w_5	0.24
w_6	0.21

Table A.22 Weighted normalized decision matrix of TOPSIS application for 1350 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.015396	0.003609	0.000712	0.016403	0.017369	0.014991
Alt2	0.015338	0.003582	0.000606	0.015378	0.016237	0.014159
Alt3	0.015361	0.003609	0.000493	0.015378	0.016180	0.014159
Alt4	0.015384	0.003664	0.000485	0.015378	0.016180	0.014159
Alt5	0.015442	0.003718	0.000720	0.015172	0.015570	0.013743
.	.	.	.	.	.	.
Alt135	0.015809	0.004238	0.000615	0.015719	0.017104	0.019472
.	.	.	.	.	.	.
Alt181	0.015534	0.003445	0.000606	0.012985	0.013590	0.011849
.	.	.	.	.	.	.
Alt255	0.015660	0.003800	0.000623	0.014694	0.015056	0.013258
Alt256	0.015775	0.003390	0.000655	0.014352	0.014642	0.012981
Alt257	0.015809	0.003691	0.000631	0.014352	0.014731	0.013097
Alt258	0.015740	0.003800	0.000590	0.014694	0.015004	0.013258
Alt259	0.015625	0.003582	0.000647	0.014352	0.014807	0.013004

Table A.23 Calculation of positive and negative ideal solution of TOPSIS application for 1350 DEN ATY Samples with DEMATEL weights

	C1	C2	C3	C4	C5	C6
A^+	0.0163	0.0065	0.0007	0.0164	0.0174	0.0195
A^-	0.0148	0.0031	0.0004	0.0130	0.0130	0.0118

Table A.24 The distance of each alternative to the positive ideal solution of TOPSIS application for 1350 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000025	0.000008	0.000000	0.000000	0.000000	0.000020	0.007314
Alt2	0.000025	0.000008	0.000000	0.000001	0.000001	0.000028	0.007973
Alt3	0.000025	0.000008	0.000000	0.000001	0.000001	0.000028	0.007988
Alt4	0.000025	0.000008	0.000000	0.000001	0.000001	0.000028	0.007983
Alt5	0.000026	0.000007	0.000000	0.000002	0.000003	0.000033	0.008416
.	.	.	.	.	.	.	.
Alt135	0.000030	0.000005	0.000000	0.000000	0.000000	0.000000	0.005926
.	.	.	.	.	.	.	.
Alt181	0.000027	0.000009	0.000000	0.000012	0.000014	0.000058	0.010948
.	.	.	.	.	.	.	.
Alt255	0.000028	0.000007	0.000000	0.000003	0.000005	0.000039	0.009054
Alt256	0.000029	0.000009	0.000000	0.000004	0.000007	0.000042	0.009614
Alt257	0.000030	0.000008	0.000000	0.000004	0.000007	0.000041	0.009440
Alt258	0.000029	0.000007	0.000000	0.000003	0.000006	0.000039	0.009115
Alt259	0.000028	0.000008	0.000000	0.000004	0.000007	0.000042	0.009410

Table A.25 The distance of each alternative to the negative ideal solution of TOPSIS application for 1350 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000000	0.000000	0.000000	0.000012	0.000019	0.000010	0.006445
Alt2	0.000000	0.000000	0.000000	0.000006	0.000011	0.000005	0.004717
Alt3	0.000000	0.000000	0.000000	0.000006	0.000010	0.000005	0.004681
Alt4	0.000000	0.000000	0.000000	0.000006	0.000010	0.000005	0.004690
Alt5	0.000000	0.000000	0.000000	0.000005	0.000007	0.000004	0.004000
.	.	.	.	.	.	.	.
Alt135	0.000001	0.000001	0.000000	0.000007	0.000017	0.000058	0.009220
.	.	.	.	.	.	.	.
Alt181	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.001038
.	.	.	.	.	.	.	.
Alt255	0.000001	0.000001	0.000000	0.000003	0.000004	0.000002	0.003244
Alt256	0.000001	0.000000	0.000000	0.000002	0.000003	0.000001	0.002647
Alt257	0.000001	0.000000	0.000000	0.000002	0.000003	0.000002	0.002816
Alt258	0.000001	0.000001	0.000000	0.000003	0.000004	0.000002	0.003231
Alt259	0.000001	0.000000	0.000000	0.000002	0.000003	0.000001	0.002744

Table A.26 Calculation of relative proximity of TOPSIS application for 1350 DEN ATY Samples with DEMATEL weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.006445	0.007314	0.468437
Alt2	0.004717	0.007973	0.371716
Alt3	0.004681	0.007988	0.369485
Alt4	0.004690	0.007983	0.370085
Alt5	0.004000	0.008416	0.322165
.	.	.	.
Alt135	0.009220	0.005926	0.608756
.	.	.	.
Alt181	0.001038	0.010948	0.086588
.	.	.	.
Alt255	0.003244	0.009054	0.263791
Alt256	0.002647	0.009614	0.215899
Alt257	0.002816	0.009440	0.229768
Alt258	0.003231	0.009115	0.261722
Alt259	0.002744	0.009410	0.225762

Table A.27 Ranking of 1350 DEN ATY samples with TOPSIS method and DEMATEL weights

Ranking	Alternative	C_i^*
Best alternative	Alt135	0.608756
Worst Alternative	Alt181	0.086588

Table A.28 Decision matrix of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1340	13.20	8.80	4.80	43.25	6.49
Alt2	1335	13.10	7.50	4.50	40.43	6.13
Alt3	1337	13.20	6.10	4.50	40.29	6.13
Alt4	1339	13.40	6.00	4.50	40.29	6.13
Alt5	1344	13.60	8.90	4.40	38.77	5.95
.	.	.	.	.	.	.
Alt135	1376	15.50	7.60	4.60	42.59	8.43
.	.	.	.	.	.	.
Alt181	1352	12.60	7.50	3.80	33.84	5.13
.	.	.	.	.	.	.
Alt255	1363	13.90	7.70	4.30	37.49	5.74
Alt256	1373	12.40	8.10	4.20	36.46	5.62
Alt257	1376	13.50	7.80	4.20	36.68	5.67
Alt258	1370	13.90	7.30	4.30	37.36	5.74
Alt259	1360	13.10	8.00	4.20	36.87	5.63

Table A.29 Normalized decision matrix of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0483	0.0371	0.0451	0.0494	0.0502	0.0607
Alt2	0.0481	0.0368	0.0384	0.0463	0.0469	0.0573
Alt3	0.0482	0.0371	0.0313	0.0463	0.0468	0.0573
Alt4	0,0483	0.0377	0.0307	0.0463	0.0468	0.0573
Alt5	0,0484	0.0382	0.0456	0.0457	0.0450	0.0556
.	.	.	.	.	.	.
Alt1135	0.0496	0.0436	0.0389	0.0473	0.0494	0.0788
.	.	.	.	.	.	.
Alt181	0.0487	0.0354	0.0384	0.0391	0.0393	0.0480
.	.	.	.	.	.	.
Alt255	0.0491	0.0391	0.0395	0.0442	0.0435	0.0537
Alt256	0.0495	0.0349	0.0415	0.0432	0.0423	0.0525
Alt257	0.0496	0.0380	0.0400	0.0432	0.0426	0.0530
Alt258	0.0494	0.0391	0.0374	0.0442	0.0434	0.0537
Alt259	0.0490	0.0368	0.0410	0.0432	0.0428	0.0526

Table A.30 Weights of each criterion of TOPSIS application for 1350 DEN ATY samples (with equal weights)

Weights	**Value**
w_1	0.166
w_2	0.166
w_3	0.166
w_4	0.166
w_5	0.166
w_6	0.166

Table A.31 Weighted normalized decision matrix of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.008018	0.006161	0.007486	0.008197	0.008332	0.010070
Alt2	0.007988	0.006114	0.006380	0.007684	0.007789	0.009512
Alt3	0.008000	0.006161	0.005189	0.007684	0.007762	0.009512
Alt4	0.008012	0.006254	0.005104	0.007684	0.007762	0.009512
Alt5	0.008042	0.006347	0.007571	0.007582	0.007469	0.009232
.	.	.	.	.	.	.
Alt135	0.008234	0.007234	0.006465	0.007855	0.008205	0.013080
.	.	.	.	.	.	.
Alt181	0.008090	0.005881	0.006380	0.006489	0.006519	0.007960
.	.	.	.	.	.	.
Alt255	0.008156	0.006487	0.006550	0.007343	0.007222	0.008906
Alt256	0.008216	0.005787	0.006890	0.007172	0.007024	0.008720
Alt257	0.008234	0.006301	0.006635	0.007172	0.007066	0.008798
Alt258	0.008198	0.006487	0.006210	0.007343	0.007197	0.008906
Alt259	0.008138	0.006114	0.006805	0.007172	0.007103	0.008736

Table A.32 Calculation of positive and negative ideal solution of TOPSIS application for 1350 DEN ATY samples with equal weights

	C1	C2	C3	C4	C5	C6
A^+	0.0085	0.0110	0.0076	0.0081	0.0083	0.0131
A^-	0.0077	0.0052	0.0044	0.0065	0.0062	0.0080

Table A.33 The distance of each alternative to the positive ideal solution of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000001	0.003023	0.000000	0.000000	0.000001	0.000003	0.055028
Alt2	0.000001	0.003028	0.000002	0.000000	0.000000	0.000001	0.055065
Alt3	0.000001	0.003023	0.000006	0.000000	0.000000	0.000001	0.055059
Alt4	0.000001	0.003013	0.000007	0.000000	0.000000	0.000001	0.054970
Alt5	0.000001	0.003002	0.000000	0.000000	0.000000	0.000001	0.054812
.	.	.	.	.	.	.	.
Alt135	0.000002	0.002906	0.000001	0.000000	0.000001	0.000022	0.054145
.	.	.	.	.	.	.	.
Alt181	0.000001	0.003054	0.000002	0.000001	0.000001	0.000000	0.055308
.	.	.	.	.	.	.	.
Alt255	0.000002	0.002987	0.000001	0.000000	0.000000	0.000000	0.054683
Alt256	0.000002	0.003064	0.000001	0.000000	0.000000	0.000000	0.055379
Alt257	0.000002	0.003007	0.000001	0.000000	0.000000	0.000000	0.054870
Alt258	0.000002	0.002987	0.000002	0.000000	0.000000	0.000000	0.054692
Alt259	0.000002	0.003028	0.000001	0.000000	0.000000	0.000000	0.055051

Table A.34 The distance of each alternative to the negative ideal solution of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000003	0.000001	0.000005	0.000007	0.000008	0.000018	0.006595
Alt2	0.000003	0.000001	0.000001	0.000005	0.000006	0.000014	0.005442
Alt3	0.000003	0.000001	0.000000	0.000005	0.000005	0.000014	0.005312
Alt4	0.000003	0.000002	0.000000	0.000005	0.000005	0.000014	0.005337
Alt5	0.000003	0.000002	0.000006	0.000004	0.000004	0.000012	0.005549
.	.	.	.	.	.	.	.
Alt135	0.000004	0.000005	0.000002	0.000006	0.000008	0.000053	0.008736
.	.	.	.	.	.	.	.
Alt181	0.000003	0.000001	0.000001	0.000001	0.000001	0.000005	0.003504
.	.	.	.	.	.	.	.
Alt255	0.000004	0.000002	0.000002	0.000004	0.000003	0.000009	0.004875
Alt256	0.000004	0.000001	0.000003	0.000003	0.000003	0.000008	0.004595
Alt257	0.000004	0.000002	0.000002	0.000003	0.000003	0.000009	0.004691
Alt258	0.000004	0.000002	0.000001	0.000004	0.000003	0.000009	0.004799
Alt259	0.000004	0.000001	0.000003	0.000003	0.000003	0.000008	0.004634

Table A.35 Calculation of relative proximity of TOPSIS application for 1350 DEN ATY samples with equal weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.006595	0.055028	0.107029
Alt2	0.005442	0.055065	0.089947
Alt3	0.005312	0.055059	0.087993
Alt4	0.005337	0.054970	0.088502
Alt5	0.005549	0.054812	0.091932
.	.	.	.
Alt135	0.008736	0.054145	0.138926
.	.	.	.
Alt181	0.003504	0.055308	0.059576
.	.	.	.
Alt255	0.004875	0.054683	0.081861
Alt256	0.004595	0.055379	0.076619
Alt257	0.004691	0.054870	0.078756
Alt258	0.004799	0.054692	0.080671
Alt259	0.004634	0.055051	0.077643

Table A.36 Ranking of 1350 DEN ATY samples with TOPSIS method and equal weights

Ranking	Alternative	C_i^*
Best alternative	Alt135	0.138926
Worst Alternative	Alt181	0.059576

Table A.37 Decision matrix of TOPSIS application for 1600 DEN ATY samples with DEMATEL weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1579	12.60	6.90	4.60	41.46	7.34
Alt2	1632	10.60	8.70	3.80	32.92	6.03
Alt3	1630	13.30	7.10	4.50	35.59	7.15
Alt4	1629	12.70	8.10	4.10	34.87	6.49
Alt5	1625	13.10	7.80	4.10	36.61	6.60
.	.	.	.	.	.	.
Alt13	1650	11.20	6.80	3.80	33.02	6.05
.	.	.	.	.	.	.
Alt138	1624	13.60	6.90	4.00	34.72	6.33
Alt139	1669	13.40	6.90	4.00	34.37	6.41
Alt140	1687	13.60	7.60	3.90	33.35	6.29
Alt141	1676	14.10	7.60	4.10	35.35	6.63
Alt142	1684	13.80	6.30	4.00	33.86	6.40

Table A.38 Normalized decision matrix of TOPSIS application for 1600 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0797	0.0607	0.0764	0.0971	0.1019	0.0969
Alt2	0.0824	0.0511	0.0963	0.0802	0.0809	0.0796
Alt3	0.0823	0.0641	0.0786	0.0950	0.0949	0.0944
Alt4	0,0822	0.0612	0.0897	0.0866	0.0857	0.0857
Alt5	0,0820	0.0631	0.0863	0.0866	0.0900	0.0871
.	.	.	.	.	.	.
Alt13	0.0833	0.0540	0.0753	0.0802	0.0812	0.0799
.	.	.	.	.	.	.
Alt138	0.0820	0.0655	0.0764	0.0845	0.0854	0.0836
Alt139	0.0842	0.0646	0.0764	0.0845	0.0845	0.0846
Alt140	0.0851	0.0655	0.0841	0.0824	0.0820	0.0830
Alt141	0.0846	0.0679	0.0841	0.0866	0.0869	0.0875
Alt142	0.0850	0.0665	0.0697	0.0845	0.0833	0.0845

Table A.39 Weights of each criterion of TOPSIS application for 1600 DEN ATY samples (with DEMATEL weights)

Weights	**Value**
w_1	0.25
w_2	0.06
w_3	0.01
w_4	0.23
w_5	0.24
w_6	0.21

Table A.40 Weighted normalized decision matrix of TOPSIS application for 1600 DEN ATY samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.019923	0.004719	0.000764	0.022340	0.024467	0.020348
Alt2	0.020592	0.003970	0.000963	0.018455	0.019427	0.016716
Alt3	0.020567	0.004981	0.000786	0.021855	0.022773	0.019821
Alt4	0.020554	0.004757	0.000897	0.019912	0.020578	0.017991
Alt5	0.020504	0.004906	0.000863	0.019912	0.021605	0.018296
.	.	.	.	.	.	.
Alt13	0.020819	0.004195	0.000753	0.018455	0.019486	0.016772
.	.	.	.	.	.	.
Alt24	0.020605	0.004382	0.000963	0.017969	0.019120	0.016467
.	.	.	.	.	.	.
Alt138	0.020491	0.005094	0.000764	0.019426	0.020489	0.017548
Alt139	0.021059	0.005019	0.000764	0.019426	0.020283	0.017769
Alt140	0.021286	0.005094	0.000841	0.018941	0.019681	0.017437
Alt141	0.021147	0.005281	0.000841	0.019912	0.020861	0.018379
Alt142	0.021248	0.005169	0.000697	0.019426	0.019982	0.017742

Table A.41 Calculation of positive and negative ideal solution of TOPSIS application for 1600 DEN ATY Samples with DEMATEL weights

	C1	C2	C3	C4	C5	C6
A^+	0.0216	0.0057	0.0010	0.0223	0.0244	0.0203
A^-	0.0199	0.0040	0.0006	0.0180	0.0184	0.0162

Table A.42 The distance of each alternative to the positive ideal solution of TOPSIS application for 1600 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000003	0.000001	0.000000	0.000000	0.000000	0.000000	0.001948
Alt2	0.000001	0.000003	0.000000	0.000015	0.000001	0.000025	0.007599
Alt3	0.000001	0.000001	0.000000	0.000000	0.000001	0.000003	0.002234
Alt4	0.000001	0.000001	0.000000	0.000006	0.000001	0.000015	0.005345
Alt5	0.000001	0.000001	0.000000	0.000006	0.000003	0.000008	0.004487
.	.	.	.	.	.	.	.
Alt13	0.000001	0.000002	0.000000	0.000015	0.000025	0.000013	0.007461
.	.	.	.	.	.	.	.
Alt24	0.000001	0.000002	0.000000	0.000019	0.000029	0.000015	0.008094
.	.	.	.	.	.	.	.
Alt138	0.000001	0.000000	0.000000	0.000008	0.000016	0.000008	0.005812
Alt139	0.000000	0.000001	0.000000	0.000008	0.000018	0.000007	0.005784
Alt140	0.000000	0.000000	0.000000	0.000012	0.000023	0.000008	0.006591
Alt141	0.000000	0.000000	0.000000	0.000006	0.000013	0.000004	0.004814
Alt142	0.000000	0.000000	0.000000	0.000008	0.000020	0.000007	0.005991

Table A.43 The distance of each alternative to the negative ideal solution of TOPSIS application for 1600 DEN ATY Samples with DEMATEL weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000000	0.000001	0.000000	0.000019	0.000036	0.000017	0.008547
Alt2	0.000000	0.000000	0.000000	0.000000	0.000001	0.000000	0.001424
Alt3	0.000000	0.000001	0.000000	0.000015	0.000019	0.000013	0.006951
Alt4	0.000000	0.000001	0.000000	0.000004	0.000005	0.000003	0.003548
Alt5	0.000000	0.000001	0.000000	0.000004	0.000010	0.000004	0.004402
.	.	.	.	.	.	.	.
Alt13	0.000001	0.000000	0.000000	0.000000	0.000001	0.000000	0.001584
.	.	.	.	.	.	.	.
Alt24	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001132
.	.	.	.	.	.	.	.
Alt138	0.000000	0.000001	0.000000	0.000002	0.000004	0.000002	0.003114
Alt139	0.000001	0.000001	0.000000	0.000002	0.000003	0.000002	0.003215
Alt140	0.000002	0.000002	0.000000	0.000001	0.000002	0.000001	0.002672
Alt141	0.000001	0.000002	0.000000	0.000004	0.000006	0.000005	0.004192
Alt142	0.000002	0.000001	0.000000	0.000002	0.000002	0.000002	0.003166

Table A.44 Calculation of relative proximity of TOPSIS application for 1600 DEN ATY Samples with DEMATEL weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.008547	0.001948	0.814429
Alt2	0.001424	0.007599	0.157849
Alt3	0.006951	0.002234	0.756740
Alt4	0.003548	0.005345	0.398931
Alt5	0.004402	0.004487	0.495221
.	.	.	.
Alt13	0.001584	0.007461	0.175104
.	.	.	.
Alt24	0.001132	0.008094	0.122731
.	.	.	.
Alt138	0.003114	0.005812	0.348874
Alt139	0.003215	0.005784	0.357259
Alt140	0.002672	0.006591	0.288489
Alt141	0.004192	0.004814	0.465490
Alt142	0.003166	0.005991	0.345714

Table A.45 Ranking of 1600 DEN ATY samples with TOPSIS method and DEMATEL weights

Ranking	Alternative	C_i^*
Best alternative	Alt1	0.814429
Worst Alternative	Alt24	0.122731

Table A.46 Decision matrix of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	Count	Elongation	Shrinkage	Tenacity	RKM	Breaking Force
Alt1	1579	12.60	6.90	4.60	41.46	7.34
Alt2	1632	10.60	8.70	3.80	32.92	6.03
Alt3	1630	13.30	7.10	4.50	35.59	7.15
Alt4	1629	12.70	8.10	4.10	34.87	6.49
Alt5	1625	13.10	7.80	4.10	36.61	6.60
.	.	.	.	.	.	.
Alt13	1650	11.20	6.80	3.80	33.02	6.05
.	.	.	.	.	.	.
Alt138	1624	13.60	6.90	4.00	34.72	6.33
Alt139	1669	13.40	6.90	4.00	34.37	6.41
Alt140	1687	13.60	7.60	3.90	33.35	6.29
Alt141	1676	14.10	7.60	4.10	35.35	6.63
Alt142	1684	13.80	6.30	4.00	33.86	6.40

Table A.47 Normalized decision matrix of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.0797	0.0607	0.0764	0.0971	0.1019	0.0969
Alt2	0.0824	0.0511	0.0963	0.0802	0.0809	0.0796
Alt3	0.0823	0.0641	0.0786	0.0950	0.0949	0.0944
Alt4	0,0822	0.0612	0.0897	0.0866	0.0857	0.0857
Alt5	0,0820	0.0631	0.0863	0.0866	0.0900	0.0871
.	.	.	.	.	.	.
Alt113	0.0833	0.0540	0.0753	0.0802	0.0812	0.0799
.	.	.	.	.	.	.
Alt138	0.0820	0.0655	0.0764	0.0845	0.0854	0.0836
Alt139	0.0842	0.0646	0.0764	0.0845	0.0845	0.0846
Alt140	0.0851	0.0655	0.0841	0.0824	0.0820	0.0830
Alt141	0.0846	0.0679	0.0841	0.0866	0.0869	0.0875
Alt142	0.0850	0.0665	0.0697	0.0845	0.0833	0.0845

Table A.48 Weights of each criterion of TOPSIS application for 1600 DEN ATY samples (with equal weights)

Weights	**Value**
w_1	0.166
w_2	0.166
w_3	0.166
w_4	0.166
w_5	0.166
w_6	0.166

Table A.49 Weighted normalized decision matrix of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6
Alt1	0.013229	0.010078	0.012679	0.016124	0.016923	0.016084
Alt2	0.013673	0.008478	0.015987	0.013320	0.013437	0.013214
Alt3	0.013656	0.010637	0.013047	0.015773	0.015752	0.015668
Alt4	0.013648	0.010158	0.014885	0.014371	0.014233	0.014222
Alt5	0.013614	0.010477	0.014333	0.014371	0.014943	0.014463
.	.	.	.	.	.	.
Alt13	0.013824	0.008958	0.012496	0.013320	0.013478	0.013257
.	.	.	.	.	.	.
Alt138	0.013606	0.010877	0.012679	0.014021	0.014172	0.013871
Alt139	0.013983	0.010717	0.012679	0.014021	0.014029	0.014046
Alt140	0.014134	0.010877	0.013966	0.013670	0.013613	0.013783
Alt141	0.014042	0.011277	0.013966	0.014371	0.014429	0.014528
Alt142	0.014109	0.011037	0.011577	0.014021	0.013821	0.014024

Table A.50 Calculation of positive and negative ideal solution of TOPSIS application for 1600 DEN ATY samples with equal weights

	C1	C2	C3	C4	C5	C6
A^+	0.0143	0.0122	0.0160	0.0161	0.0169	0.0161
A^-	0.0132	0.0085	0.0101	0.0130	0.0128	0.0128

Table A.51 The distance of each alternative to the positive ideal solution of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^*
Alt1	0.000001	0.009211	0.000011	0.000000	0.000000	0.000000	0.096040
Alt2	0.000000	0.009521	0.000000	0.000008	0.000012	0.000008	0.097723
Alt3	0.000000	0.009104	0.000009	0.000000	0.000001	0.000000	0.095473
Alt4	0.000000	0.009196	0.000001	0.000003	0.000007	0.000003	0.095977
Alt5	0.000001	0.009135	0.000003	0.000003	0.000004	0.000003	0.095644
.	.	.	.	.	.	.	.
Alt13	0.000000	0.009428	0.000012	0.000008	0.000012	0.000008	0.097303
.	.	.	.	.	.	.	.
Alt138	0.000001	0.009059	0.000011	0.000004	0.000008	0.000005	0.095325
Alt139	0.000000	0.009089	0.000011	0.000004	0.000008	0.000004	0.095483
Alt140	0.000000	0.009059	0.000004	0.000006	0.000011	0.000005	0.095315
Alt141	0.000000	0.008983	0.000004	0.000003	0.000006	0.000002	0.094860
Alt142	0.000000	0.009028	0.000019	0.000004	0.000010	0.000004	0.095215

Table A.52 The distance of each alternative to the negative ideal solution of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	C1	C2	C3	C4	C5	C6	S_i^-
Alt1	0.000000	0.000003	0.000007	0.000010	0.000017	0.000011	0.006868
Alt2	0.000000	0.000000	0.000035	0.000000	0.000000	0.000000	0.005960
Alt3	0.000000	0.000005	0.000009	0.000008	0.000009	0.000008	0.006201
Alt4	0.000000	0.000003	0.000023	0.000002	0.000002	0.000002	0.005652
Alt5	0.000000	0.000004	0.000018	0.000002	0.000005	0.000003	0.005609
.	.	.	.	.	.	.	.
Alt13	0.000000	0.000000	0.000006	0.000000	0.000001	0.000000	0.002670
.	.	.	.	.	.	.	.
Alt138	0.000000	0.000006	0.000007	0.000001	0.000002	0.000001	0.004091
Alt139	0.000001	0.000005	0.000007	0.000001	0.000002	0.000002	0.004054
Alt140	0.000001	0.000006	0.000015	0.000000	0.000001	0.000001	0.004860
Alt141	0.000001	0.000008	0.000015	0.000002	0.000003	0.000003	0.005575
Alt142	0.000001	0.000007	0.000002	0.000001	0.000001	0.000001	0.003630

Table A.53 Calculation of relative proximity of TOPSIS application for 1600 DEN ATY samples with equal weights

Alternatives	S_i^-	S_i^*	C_i^*
Alt1	0.006868	0.096040	0.066735
Alt2	0.005960	0.097723	0.057480
Alt3	0.006201	0.095473	0.060986
Alt4	0.005652	0.095977	0.055610
Alt5	0.005609	0.095644	0.055399
.	.	.	.
Alt13	0.002670	0.097303	0.026706
.	.	.	.
Alt138	0.004091	0.095325	0.041151
Alt139	0.004054	0.095483	0.040731
Alt140	0.004860	0.095315	0.048519
Alt141	0.005575	0.094860	0.055506
Alt142	0.003630	0.095215	0.036728

Table A.54 Ranking of 1600 DEN ATY samples with TOPSIS method and equal weights

Ranking	Alternative	C_i^*
Best alternative	Alt1	0.066735
Worst Alternative	Alt13	0.026706