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A Novel Integrated Expert System Modelling Approach for Sugarcane Management

Sidra Gul[1], Noaman Ul Haq[1], Abdur Rashid Khan[1]
[1]Department of Physical and Numerical Sciences, Qurtuba University of Science & IT, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan.
*Correspondence: sidragul1702@gmail.com

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Statistics in Pakistan show that sugarcane, cultivated in tropical and subtropical areas, produced 1.9 billion tons in 2020, achieving the highest position in the world. The existing practices and processes of sugarcane management are lacking in efficiency and effectiveness, which are time-consuming and wasteful, wastage of money with improper management, creating issues of conflicts among farmers, workers, and mill administration. To overcome this significant concern, there is a dire need for an intelligent management system that could integrate the various tools, techniques, and technologies to achieve the objectives of adequate information for making rational decisions by minimizing time, cost, and optimizing the utilization of resources. The study includes: firstly, acquiring the Knowledge about the problem domain, i.e., Sugarcane Management System's key factors, tools, and techniques, as well as SWOT (Strengths Weakness Opportunity Threat) analysis to identify the gap. Secondly, to analyze and find priorities of the key factors and criteria weights through AHP (Analytical Hierarchy Process). Thirdly, to model the whole knowledge in different forms, like Decision Table, Weight Allocation Table, Decision Tree, and Conceptual Model etc. Finally, developing a prototype Rule-Based Expert System named ESFSMS (Expert System for Sugarcane Management System) and testing the proposed model through ESFSMS. The final report shows that the aggregate weight of all the factors equals 0.9995, which is nearly equal to 1.00, i.e., the goal. It is limited to a few factors, which can be extended in further research studies and the usage of modern techniques.

Keywords: AHP (Analytical Hierarchy Process), SWOT (Strengths Weakness Opportunity Threat), ES (Expert System), ESTA (Expert System Shell for Text Animation), ESFSMS (Expert System for Sugarcane Management System)

Introduction:

The world's most important crop, sugarcane, is cultivated in tropical and subtropical regions and will yield 1.9 billion tons in 2020. 40% of the world's production comes from Brazil. Sugarcane accounts for 79% of global sugar production, with sugar beets providing the majority of the remaining amount. About 70% of the sugar produced comes from hybrids of the Saccharum officinarum plant. The majority of commercial cultivars of sugarcane are complex hybrids, and all kinds are capable of crossbreeding [1]. Sugarcane is a significant cash crop for Pakistan's sugar industry because of its high value. It adds 2.9% of the total value added in agriculture and around 0.6% to the GDP. It serves as a source of energy and power and generates massive profits for the government [2]. By monitoring and guiding the relationship with the farmers, the sugarcane management system ensures that customers obtain high-quality products, encourages financial benefits, and improves the system's trackability [3].

The existing practices and processes of sugarcane management consist of various factors, like cutting sugarcane, storage of sugarcane, transportation, delivery of sugarcane, financial management, and many other complex ongoing management processes, like planning, scheduling, organizing, etc., that are coherent, interdependent, and interrelated among each other. As per preliminary study, observation and discussions with farmers, brokers and cane staff of sugar mill, we arrived at the result that the existing practices of the sugarcane management are mostly not properly managed which are time consuming and costly creating conflicts among farmers, workers and mills administration which is the gap in the existing system to develop a model to integrate the Sugarcane Management System with modern tools of analysis, i.e, AHP (Analytic Hierarchy Process) and Expert System technology of AI that might improve the existing system with achieving maximum satisfaction of all the stakeholders to resolve these issues intelligently.

Literature Review:

The process by which an organization establishes and preserves a collaborative environment, intending to accomplish organizational objectives, is known as management. The administration of an organization is crucial to its overall performance whenever its human and non-human resources collaborate to achieve a goal. Due to the increasing size and complexity of contemporary organizations, the concept of management has gained enormous importance in the modern period [4]. From an economic contribution point of view, the sugar production is one of the most significant industries in the world. About 80% of the sugar produced globally is contributed by the sugarcane industry. As a result, sugarcane is grown on nearly 28.3 million hectares in 90 different countries, with a global production of approximately 1.69 billion tons. Brazil and India are the two countries that produce the most sugarcane in the world, with annual productions of about 768,678,382 and 348,448,000 metric tons per year, respectively [5].

Around the world, sugarcane is grown in humid subtropical and warm temperate climates. Modern sugar enterprises typically focus on producing the most sugar possible without taking fertilization into account. Farmers typically apply nutrients at a higher rate than is necessary because doing so has negative long-term effects. Numerous nations have created effective cane fertilization methods for successful cane growing and supported their farmers in their specific situation. Sugarcane is made up of minerals, water, and organic compounds, and only needs 17 essentials for healthy growth and productivity. In general, sugarcane is impacted by the following climatic factors: temperature, relative humidity, rainfall, and sunlight [6].

An Agent-Based Model (ABM) is developed in this work to evaluate behavior and locate weak points in the sugarcane farming system. Using Fuzzy Logic and system dynamics, this ABM enables the capitalization of information by the attributes of the modelled agents, such as social aptitude and autonomy. Three phases are involved in the establishment of information networks for a dynamic assessment of agricultural risk: vulnerability indicators, crop vulnerability, and overall system vulnerability. Time series, system dynamics, uncertain parameters, and experience serve as the foundation for these networks [7].

The crop's potential for use in the production of products like crystalline white sugar makes it economically significant. Although sugarcane is a long-term crop that can be grown for 10 to 18 months, diseases are the main cause of low yields. In order to reduce losses, it is important to diagnose the disease quickly. A group of farmers interested in growing sugarcane crops tested our expert system, which we had developed using the CLIPS and Delphi programming languages, and they found it to be very helpful. With modifications to the knowledge base, the Expert System can be applied to other crop environments because of its generic nature [8].

This study investigated a novel model for predicting sugarcane yield in the Bundaberg region from the time series Landsat data. For this study, 98 cloud-free (<40%) Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) images, acquired between November 15 and July 31 (2001-2015), were taken from the freely accessible Landsat archive. The field boundary layer vector files of each year were used to mask the images, and the GNDVI was computed. The model that extracted the maximum GNDVI from Landsat imagery was found to be a workable and inexpensive method to forecast sugarcane yield in the Bundaberg region [9].

In [10], a three-step process for creating a network of supply chains for bioenergy based on sugarcane in an unpredictable environment was described. A robust mixed-integer linear programming model (MILP) was created in the second stage after the fuzzy data envelopment analysis method was applied in the first. In the last stage, an experimental analysis was conducted. A real case study from Iraq was used to assess the applicability of the developed model. Based on the objective function mean and standard deviation, the results showed that the robust model that was suggested performed better than the expected scenario model by 18% and 51%, respectively.

The purpose of this study was to assess potential areas for sugarcane plantation expansion in Lamongan. Analyzing the land's suitability using the Analytic Network Process (ANP) and its availability through an overlay analysis of different policy maps were the two main evaluation processes in this study. The three parameters with the highest weights in the ANP were rainfall (0.133), cation exchange capacity and base saturation (0.134), and soil drainage (0.181). Other uses like residence, business, agriculture, and protected areas must be considered in expansion plans [11].

In order to build a sugarcane cultivation suitability assessment system based on the analytic hierarchy process (AHP), 11 specific indicators were selected with regard to terrain factor, climate factor, and disaster factor. The requirements of sugarcane growth and development on climate, terrain, and other environmental conditions, as well as the impact of natural disasters, were taken into consideration when choosing these indicators. Elevation had the maximum contribution ratio among the 11 indicators, which included the frequency of autumn drought, precipitation during the ≥20 °C period, slope, and annual average temperature [12]. To point out the gap in the existing system, a SWOT analysis for the Sugarcane Management System is given below in Table 1.

Table 1. SWOT Analysis of Sugarcane Management System

Factors	Strengths	Weaknesses	Opportunities	Threats	References
Cutting of Sugarcane	Sugar mills are in regular operation	Staleness. Low sugar recovery. Late-mature sugarcane cutting.	Sugar mills are in operation so that the	Low sugar recovery in case of	The SWOT Analysis of all these factors of

	for sugar production.		organization earns a profit.	over-harvesting.	Sugarcane Management System is found by searching the literature, observations, and discussions with farmers, brokers, cane staff of Chashma Sugar Mill Unit-1, Dera Ismail Khan, etc.
Storage of Sugarcane	Looking after the sugar mills' machinery and its cleaning.	When the operation stopped, house losses occurred.	Time for repair and maintenance of sugar mills' machinery.	Sugarcane is diverted to other sugar mills, which is a waste of sugarcane.	
Transportation	Timely and fresh sugarcane supply to sugar mills. Sugar mills are operating regularly.	Easily divert sugarcane to any other sugar mill.	Helpful to cover the shortage of sugarcane from the outer area.	Easily move sugarcane to any other sugar mill. In case of transport shortage, the sugarcane supply schedule is disturbed.	
Delivery of Sugarcane	Growers'/Customers' satisfaction is very helpful for business progress.	Stale sugarcane delivery. Poor sugarcane quality supply.	Sugar and other buy products production and sales start.	Poor quality sugarcane supply. Staleness of sugarcane.	
Financial Management	Timely growers' payments start income generation. Loan recovery.	Delay in payments affects the sugarcane supply. Less recovery affects plans.	Achieve the company's goal. Debit all bank loans.	Poor payment issues. Less loan recovery. Lower rate of sugar.	

After thoroughly studying the literature related to the field of agriculture, especially about sugarcane management, we found a research gap after reviewing various research papers on sugarcane and using the gap analysis tool of SWOT analysis. The primary issue facing the supply chain of the sugarcane agroindustry is stakeholder coordination to increase competitive advantage. Farmers of today must be well equipped with the latest resources and technologies, which is a main issue. Proper Sugarcane resource management is generally ignored. Without proper management, issues like low productivity, poor quality, and stale sugarcane delivery, delays in payment to farmers might create conflicts among stockholders and farmers. There is a need to use the latest technologies and techniques to solve the issue, to minimize cost and time by promoting productivity and quality of services.

Aims and Objectives:

The primary goal of the study is to develop a model for a sugarcane management system by integrating the key factors with various methods, tools, and techniques. To attain this aim, the following objectives will have to be achieved.

1. To examine the key factors of sugarcane management.
2. To develop a model by integrating the key decision-making factors with SWOT analysis and AHP.
3. To develop a prototype Rule-based ES for testing and evaluation of the proposed model.

Material and Methods:

The proposed research work was divided into various phases described in the following sections. Figure 1 represents the Context view of the flow of information among these phases.

- **Key Parameter Identification:**

The first and foremost step in the problem domain was to identify the key decision-making factors (i.e, cutting of sugarcane, storage of sugarcane, transportation, delivery of sugarcane, financial management) for decision making, as well as to know about the SWOT analysis, ES technology, and AHP tool for problem solution.

- **Knowledge Acquisition:**

Detailed knowledge about the key parameters of the sugarcane management system, methods, tools, and ES technology was acquired through a heuristic approach, observation, discussion with domain experts, and literature study.

- **Analysis & Prioritization:**

The acquired data was analyzed to assign weights, and priorities were found through AHP. In that phase, the weights and importance of each decision-making component were determined to know which factor was important and how much.

- **Problem Modelling:**

The key management factors of Sugarcane Management practices and processes were integrated with SWOT analysis and AHP for the development of the proposed model that would be presented through various models, like Conceptual model, Process and functional models, Tree Diagrams, etc.

- **Model Testing and Evaluation:**

Expert System Shell for Text Animation (ESTA) was used to create a rule-based expert system. The decision-making at any stage of the proposed management process could be made easy through the proposed Expert System, which can provide explanations and consultation with reasoning capabilities.

- **Documentation:**

The whole research work had to be documented in a standard thesis format that might be saved in the library for further use and publications.

The entire Research Methodology process is shown in Figure 1, which includes selecting and understanding the problem, acquiring knowledge about the problem, performing analysis and prioritizing criteria values, preparing a model for the extracted knowledge, developing an expert system and testing the model, and finally writing the thesis.

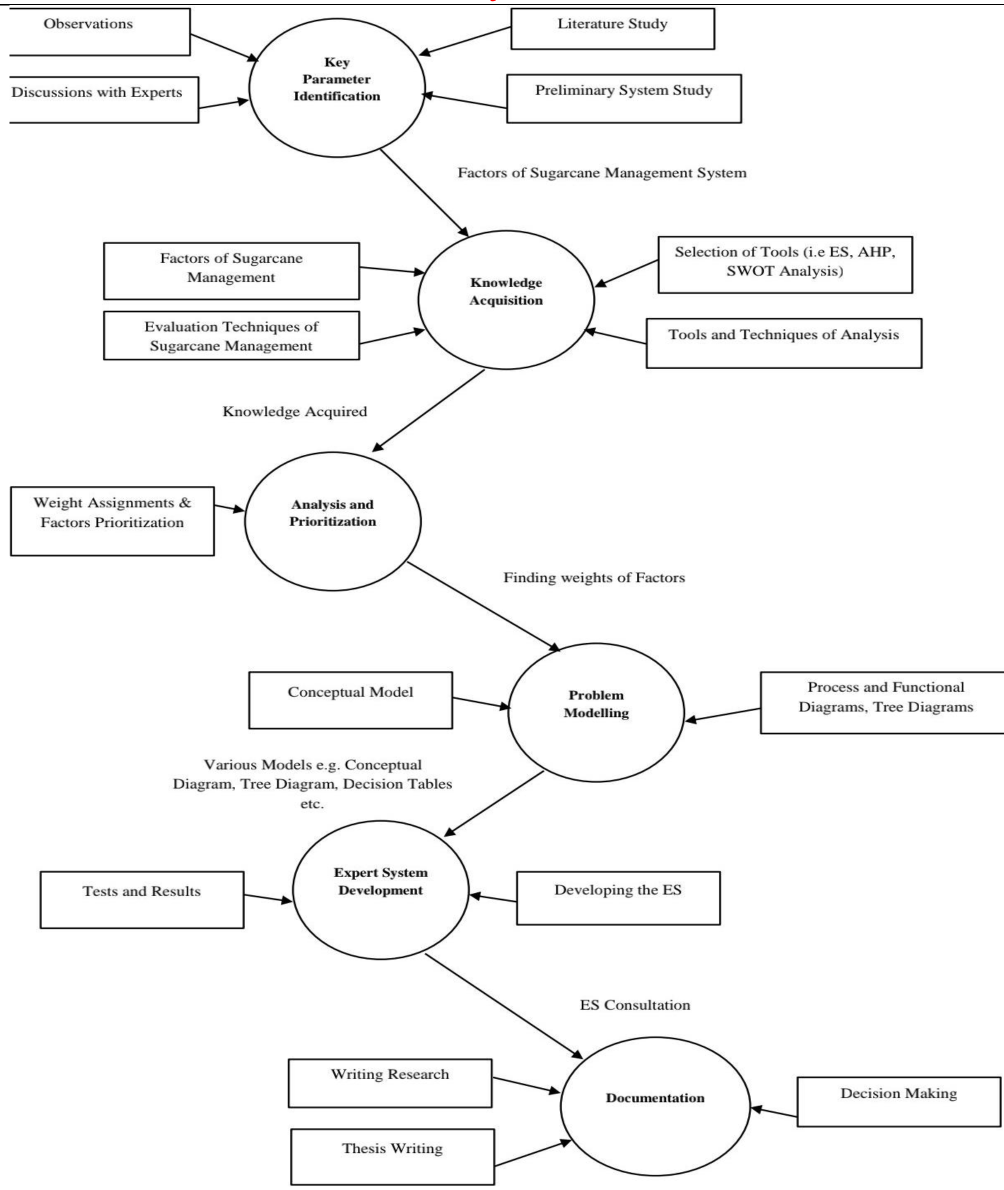

Figure 1. Context View of the Information Flow in Proposed Research Work

Modelling:

The proposed work had been depicted through various models in the form of diagrams and tables, etc., being shown in the following sections.

- **Conceptual Model:**

A Conceptual Model for the entire Sugarcane Management System was developed and shown in Figure 2. The first level shows the Sugarcane Management Factors, the second represents the Sugarcane Management Functions, third level has the IF-THEN Condition that would check the situation to be checked for whether the condition is either True or False for each criterion. In the case of True or Yes, the prescribed weight was assigned to the factor, and in case of False or no weight was assigned to the specific factor. These weights were summed up until completion, and the last level contained the value of the Sum for each criterion.

This was the main model for decision making in the proposed research work to show all the factors of sugarcane along with the Management functions being applied to these factors to achieve the objectives of whether the sum of weights of all the factors fulfills the criteria or not, i.e., 1 or 0.

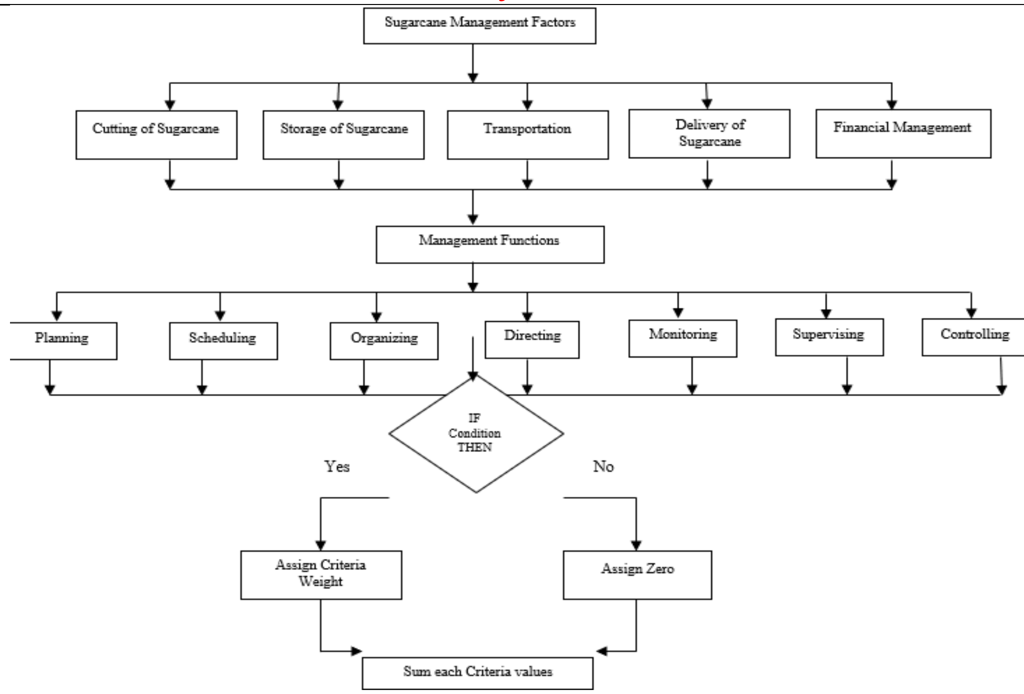

Figure 2. Conceptual Diagram of Sugarcane Management System

- **Tree Diagram of Sugarcane Management:**

This diagram was to show the proposed problem in the form of a tree that represented how the goal was achieved through passing through various stages by allocating and summing up the weights of individual factors. Figure 3 shows the Tree diagram. Weights being calculated in the AHP analysis were assigned to specific factors based on the domain experts' evaluation/ranking.

- **Sugarcane Management System Decision Table:**

Conditions were checked, and actions were taken in a decision table 2. The Sugarcane Management System Decision Table is displayed in Table 2. If the total sum of all weights was ≥ 0.40, then the system was accepted as it was according to the specified standards; otherwise, the system was rejected as it was not according to the specified standards.

Table 2. Decision Table for Sugarcane Management System

S.NO.	IF (Condition)	THEN (Action)
1.	SUGARCANE CUTTING FACTOR has a value of at LEAST 40%	Assign weight 0.4894 to Sugarcane Cutting
2.	STORAGE FACTOR OF SUGARCANE IS AT LEAST 40%	Assign weight 0.2566 to Storage of Sugarcane
3.	SUGARCANE TRANSPORTATION FACTOR has a value of at LEAST 40%	Assign weight 0.1409 to Sugarcane Transportation
4.	DELIVERY OF SUGARCANE has value, AT LEAST 40%	Assign weight 0.0621 to Delivery of Sugarcane
5.	FINANCIAL MANAGEMENT FACTOR has value, AT LEAST 40%	Assign a weight of 0.0505 to Financial Management.

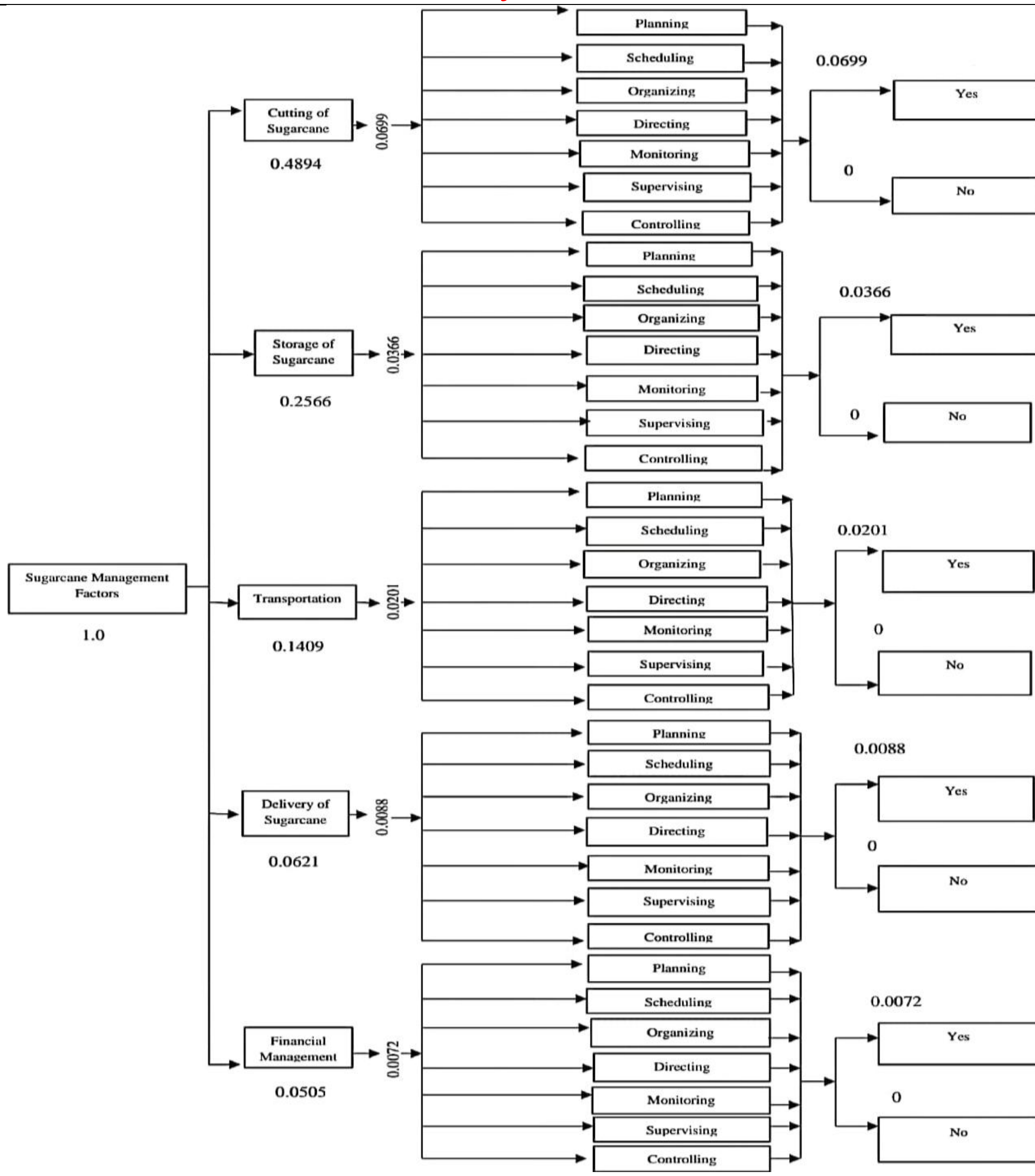

Figure 3. Tree diagram with Criteria and Alternative Selection

Results and Discussion:

According to [13], the decision-makers could model the problem in a hierarchical structure with the help of AHP. The root node of the structure contained the objective or goal, followed by criteria and alternatives.

Figure 4 shows the basic AHP structure begins with level 1, where goals are defined, level 2 represents the criteria/attributes, while level 3 shows the alternatives.

The Goal of the problem domain at level 1 was the Sugarcane Management System. Level 2 depicted the criteria in terms of the Factors of Sugarcane Management Systems (e.g., Cutting of Sugarcane, Storage, Transportation, Delivery, and Financial Management etc.). While level 3 represented the alternatives in the form of Management components, like Planning, Scheduling, Organizing, Directing, Monitoring, Supervising, and Controlling. All the factors of the Sugarcane Management system, as well as their comparison links among them, were represented through distinct colors so as to identify each factor.

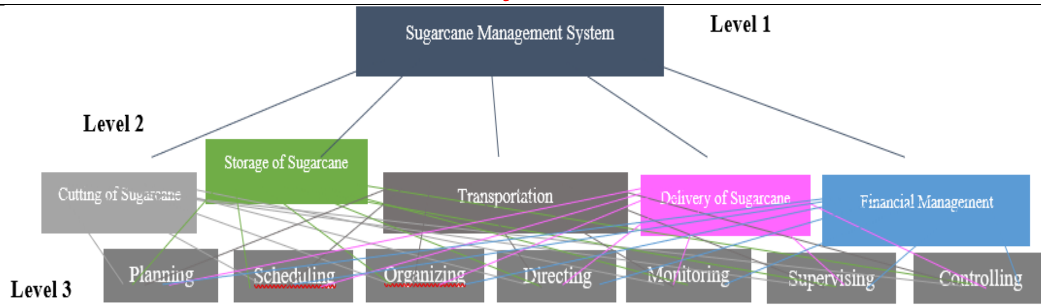

Figure 4. AHP Hierarchical Structure of Sugarcane Management System

Weights Calculation using AHP:

The following were the fundamental AHP steps, listed below. The AHP method used a nine-point scale. The scale values and their degree of preference are shown in Table 3.

Table 3. AHP Scale of Relative Importance

Scale	Degree of Preference
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2, 4, 6, 8	Intermediate Values
1/3, 1/5, 1/7, 1/9	Values for Inverse Comparison

- **Calculating Pair-Wise Comparison Matrix:**

For n distinct criteria at a level, the compared values are n(n-1)/2. In our case, the total number of criteria elements was n=5. The results of the Pair-Wise comparison were gathered in a pair-wise comparison matrix table, where each criterion was compared to the rest of the criteria. Table 4 displays the Pair-Wise Comparison matrix for Sugarcane Management.

Table 4. Sugarcane Management Pair-Wise Comparison Matrix

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	1	3	9	7	5
Storage of Sugarcane	1/3	1	5	4	6
Transportation	1/9	1/5	1	7	3
Delivery of Sugarcane	1/7	¼	1/7	1	2
Financial Management	1/5	1/6	1/3	½	1

After the pair-wise comparison, column-wise Sum was calculated, which is shown in Table 5.

Table 5. Column-Wise Sum of each Criteria

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	1	3	9	7	5
Storage of Sugarcane	0.33	1	5	4	6
Transportation	0.11	0.2	1	7	3

Delivery of Sugarcane	0.14	0.25	0.14	1	2
Financial Management	0.2	0.16	0.33	0.5	1
Sum	**1.78**	**4.61**	**15.47**	**19.5**	**17**

In order to normalize the values, Table 6 displays the division of each column value by the corresponding Sum.

Table 6. Division of each Criteria value by its Sum

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	1/1.78	3/4.61	9/15.47	7/19.5	5/17
Storage of Sugarcane	0.33/1.78	1/4.61	5/15.47	4/19.5	6/17
Transportation	0.11/1.78	0.2/4.61	1/15.47	7/19.5	3/17
Delivery of Sugarcane	0.14/1.78	0.25/4.61	0.14/15.47	1/19.5	2/17
Financial Management	0.2/1.78	0.16/4.61	0.33/15.47	0.5/19.5	1/17

- **Normalized Pair-Wise Matrix:**

After dividing each value by its column Sum, the Normalized Pair-Wise matrix was achieved, which is given in Table 7.

Table 7. Normalized Pair-Wise Matrix

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	0.5617	0.6507	0.5817	0.3589	0.2941
Storage of Sugarcane	0.1853	0.2169	0.3232	0.2051	0.3529
Transportation	0.0617	0.0433	0.0646	0.3589	0.1764
Delivery of Sugarcane	0.0786	0.0542	0.0090	0.0512	0.1176
Financial Management (Loan, Cost & Income)	0.1123	0.0347	0.0213	0.0256	0.0588

For finding the Criteria Weights, divide the sum of the whole by the total number of Criteria elements, which is shown in Table 8.

Table 8. Calculation of Criteria Weights for each Criteria

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management	**Criteria Weights**
Cutting of Sugarcane	0.5617	0.6507	0.5817	0.3589	0.2941	**0.4894**
Storage of Sugarcane	0.1853	0.2169	0.3232	0.2051	0.3529	**0.2566**
Transportation	0.0617	0.0433	0.0646	0.3589	0.1764	**0.1409**
Delivery of Sugarcane	0.0786	0.0542	0.0090	0.0512	0.1176	**0.0621**

Financial Management	0.1123	0.0347	0.0213	0.0256	0.0588	**0.0505**

- **Calculating Consistency:**

AHP consistency refers to the logical and mathematical coherence of the comparisons drawn between different criteria or alternatives. Its ability to foster stability made it extremely valuable. The multiplication of the criteria weights with non-normalized values is shown in Table 9.

Table 9. Criteria Weights Multiplication with values that are not normalized

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	1x0.4894	3x0.2566	9x0.1409	7x0.0621	5x0.0505
Storage of Sugarcane	0.33x0.4894	1x0.2566	5x0.1409	4x0.0621	6x0.0505
Transportation	0.11x0.4894	0.2x0.2566	1x0.1409	7x0.0621	3x0.0505
Delivery of Sugarcane	0.14x0.4894	0.25x0.2566	0.14x0.1409	1x0.0621	2x0.0505
Financial Management	0.2x0.4894	0.16x0.2566	0.33x0.1409	0.5x0.0621	1x0.0505

Table 10 shows the results after multiplying values by the Criteria Weights.

Table 10. Results after Multiplication

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management
Cutting of Sugarcane	0.4894	0.7698	1.2681	0.4347	0.2525
Storage of Sugarcane	0.1615	0.2566	0.7045	0.2484	0.303
Transportation	0.0538	0.0513	0.1409	0.4347	0.1515
Delivery of Sugarcane	0.0685	0.0641	0.0197	0.0621	0.101
Financial Management	0.0978	0.0410	0.0464	0.0310	0.0505

The Weighted Sum Value calculation is shown in the following Table 11.

Table 11. Calculating Weighted Sum value

	Cutting of Sugarcane	Storage of Sugarcane	Transportation	Delivery of Sugarcane	Financial Management	**Weighted Sum Value**
Cutting of Sugarcane	0.4894	0.7698	1.2681	0.4347	0.2525	**3.2145**
Storage of Sugarcane	0.1615	0.2566	0.7045	0.2484	0.303	**1.674**
Transportation	0.0538	0.0513	0.1409	0.4347	0.1515	**0.8322**
Delivery of Sugarcane	0.0685	0.0641	0.0197	0.0621	0.101	**0.3154**
Financial Management	0.0978	0.0410	0.0464	0.0310	0.0505	**0.2667**

The Total value was calculated by dividing the Weighted Sum value by the Criteria Weights represented in Table 12.

Table 12. Calculating the Total values

	Weighted Sum Value	Criteria Weights	Total
Cutting of Sugarcane	3.2145	0.4894	**6.5682**
Storage of Sugarcane	1.674	0.2566	**6.5237**
Transportation	0.8322	0.1409	**5.9063**
Delivery of Sugarcane	0.3154	0.0621	**5.0789**
Financial Management	0.2667	0.0505	**5.2811**

- **Calculating lambda max (λ):**

$$\lambda_{max} = \frac{\textbf{Sum of total weights}}{\textbf{Total number of criteria elements}} \quad .(1)$$

$$= \frac{29.3582}{5}$$

$$= 5.8716$$

The Lambda Max was computed as 5.8716 as shown above.

- **Calculating Consistency Index (C.I):**

$$\mathbf{C.I} = \frac{\lambda \mathbf{max} - \mathbf{n}}{\boldsymbol{n} - \mathbf{1}} \quad (2)$$

$$= \frac{5.8716 - 5}{5 - 1}$$

$$= 0.2179$$

The Consistency Index in our case was found as 0.2179, being shown above.

- **Calculating Consistency Ratio (R.I):**

A consistency ratio of 0.10 (C.R.) was suitable. The results were considered valid and consistent if the computed C.R. value was less than or equal to 0.10. Otherwise, results were erratic and were not used for further investigation.

$$\textbf{Consistency Ratio (CR)} = \frac{\textbf{Consistency Index}}{\textbf{Random Index}} \quad (3)$$

After finding the literature related to AHP, Table 13 shows the Random Index table, which is given below:

Table 13. Random Index Table

n	1	2	3	4	5	6	7	8	9	10
R.I	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

As the total number of criteria elements was 5, we selected the random index of 5, which was 1.12.

$$\text{CR} = \frac{0.2197}{1.12}$$

$$= 0.1$$

C.R. equal to 0.10 showed that the judgments were reliable.

After performing calculations by using the formulas of AHP, the following Criteria Weights were calculated, which are given below in Table 14:

Table 14. Final Criteria Weights Calculated with AHP

Factors/Criteria	Criteria Weights	Percentage
Cutting of Sugarcane	0.4894	48 %
Storage of Sugarcane	0.2566	25 %
Transportation	0.1409	14 %
Delivery of Sugarcane	0.0621	6 %
Financial Management	0.0505	5 %

Figure 5 shows the Column Chart Representation of Final Criteria Weights.

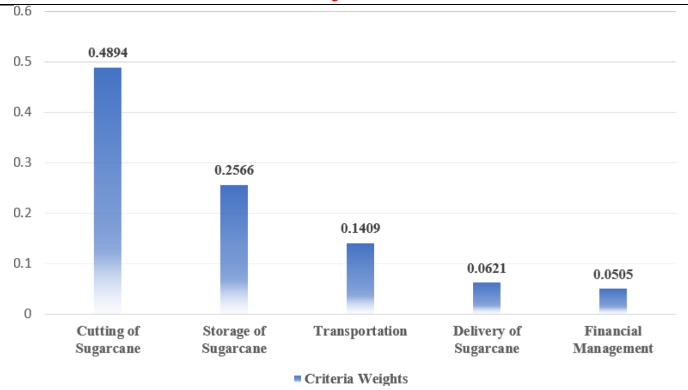

Figure 5. Column Chart Representation of Final Criteria Weights

Figure 6 shows the Pie Chart Representation for the Final Criteria Weights Percentage.

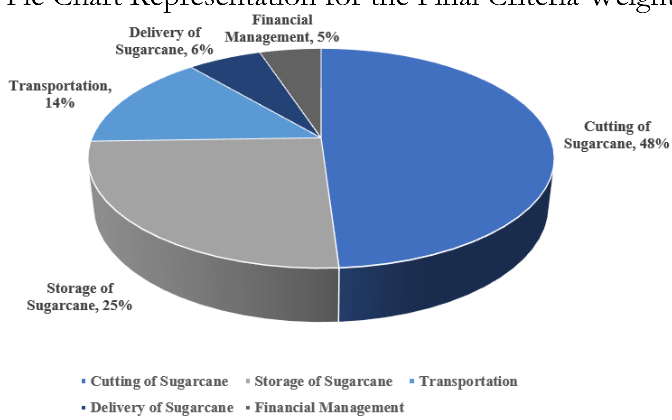

Figure 6. Pie Chart Representation of Final Criteria Weights Percentage

Testing the Proposed Model:

An ES named as an ESSMS (Expert System for Sugarcane Management System) was developed in ESTA (Expert System Shell for Text Animation), a development tool of Visual Prolog, which is a Rule-based ES, and tested for decision making in the proposed model. Rule-based ES was used to test the model due to its suitability and exact nature of the problem domain. It has been widely applied as a problem-solving module in the domains of clinical technologies, education, and agriculture.

The result of the proposed ESFSMS was achieved on the basis of the Decision Table shown above in Table 2.

The following results were the results of dialogue between the Expert System's User and the ESSMS. These menus facilitated the user to get answers to questions, like "EXPLAIN" and "WHY". Where "EXPLAIN" was related to the detail about inputs, as if there was any ambiguity for the user and they wanted to know the detail about it. While "WHY" was the answer to justify how a decision was made by the ES. The proposed ESSMS used both the Backward as well as Forward strategies of the Reasoning capability of ES through Parameters and Sections, respectively. Sections in production rules of knowledge representation played the role of Forward chaining process in the form of IF (Condition) Then Action, i.e., data-driven strategy. While Parameters were used as a Backward-chaining process in the form of an Objective that is TRUE if it fulfills the required conditions.

- **Knowledge Representation in ESTA for the Proposed ESFSMS:**

The following ESTA components were used to carry out the knowledge representation process.

Title:

The term "Title" referred to the whole knowledge base. The title could be an image or text. The Sugarcane Management System Title is shown in Figure 7.

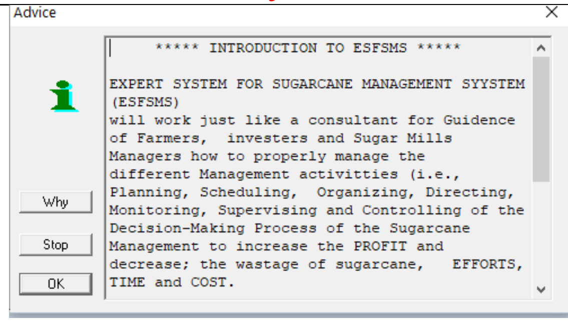

Figure 7. Title of Sugarcane Management System

Sections:

It was the highest level of knowledge representation in ESTA. "Start" referred to the first section of the knowledge base. It symbolized the numerical paragraphs or the text's literal description. It led the ESTA through statements that followed the IF-THEN or TRUE-FALSE logic. In actuality, this section contained the knowledge-based regulations. The Sugarcane Management System Section is displayed in Figure 8.

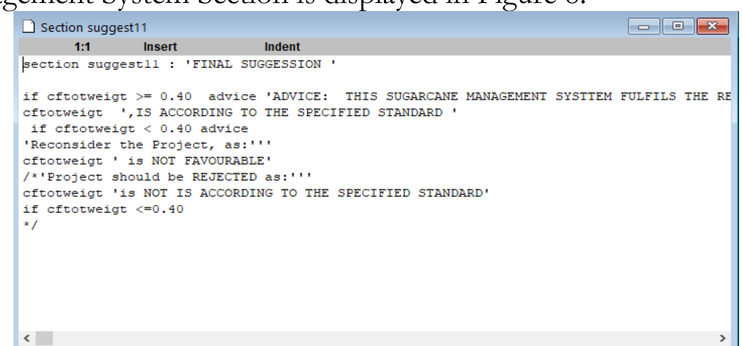

Figure 8. Section of Sugarcane Management System

Parameters:

These variables, which consist of type and declarative fields, regulate and direct the flow of control among the sections. Use of optional parameters was also provided. The type of the parameters could be Boolean, Text, Number, or Category. The Sugarcane Management System Parameter is displayed in Figure 9.

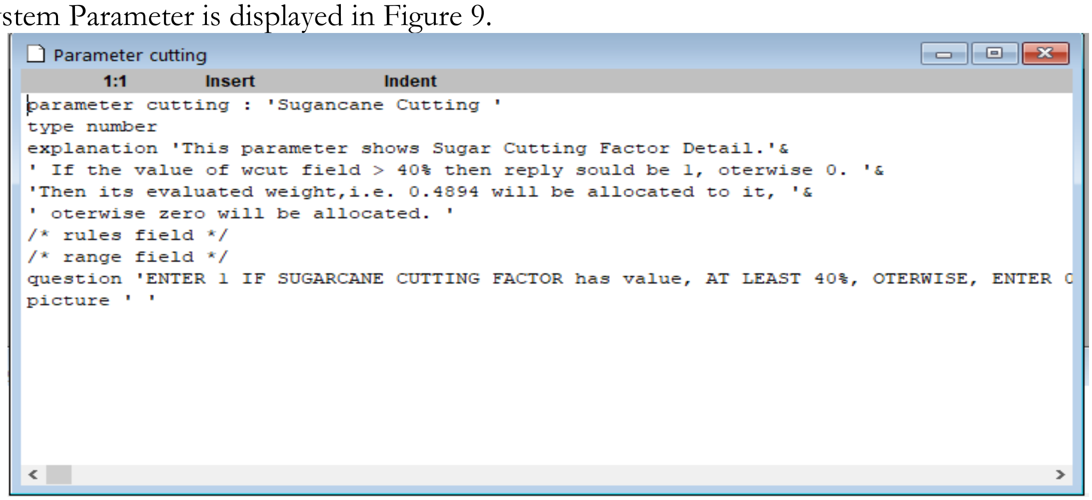

Figure 9. Parameters of the Sugarcane Management System

- **Proposed ESFSMS Final Reports in ESTA:**

These reports were generated for only the main Criteria elements of the Sugarcane Management System, which used the analogy of Decision Table 2. Values either 1 or 0 were entered by the ES user according to the situation and weights being calculated through AHP, as stated earlier, were assigned corresponding values. For example, 1 was entered as a reply to the question by the ES if the specific factor fulfilled the specified criteria. Similarly, if any factor did not fulfil the criteria, then 0 was entered.

Figure 10 represents the Explanation of the Sugarcane Cutting Factor Detail after pressing "Explain".

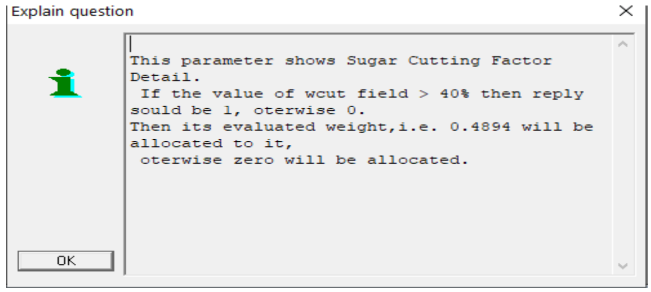

Figure 10. Parameter Sugarcane Cutting Factor Detail

Figure 11 shows the Condition for the Sugarcane Cutting Factor; the input was given as 1.

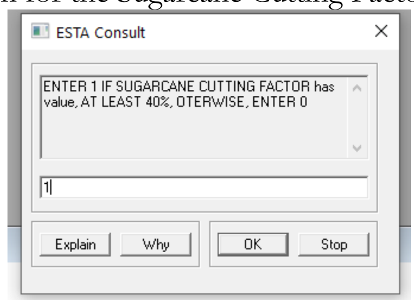

Figure 11. Condition for Sugarcane Cutting Factor

Figure 12 shows the Condition for the Storage Factor of Sugarcane.

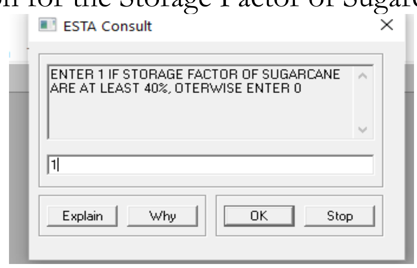

Figure 12. Conditions for the Storage Factor of Sugarcane

Figure 13 shows the conditions for Sugarcane Transportation.

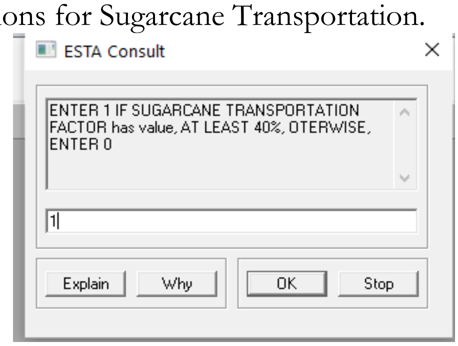

Figure 13. Conditions for Sugarcane Transportation

Figure 14 represents the Conditions for Delivery of Sugarcane.

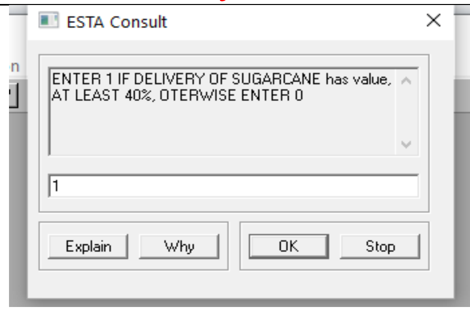

Figure 14. Conditions for the Delivery of Sugarcane

Figure 15 shows the conditions for Financial Management.

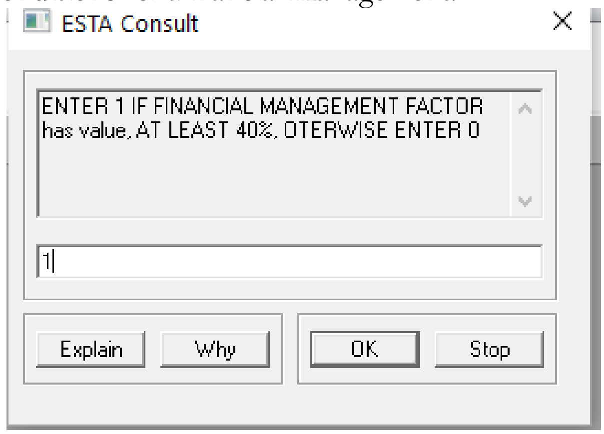

Figure 15. Conditions for Financial Management

Figure 16 shows the Summarized Weight, after calculations of all the factors.

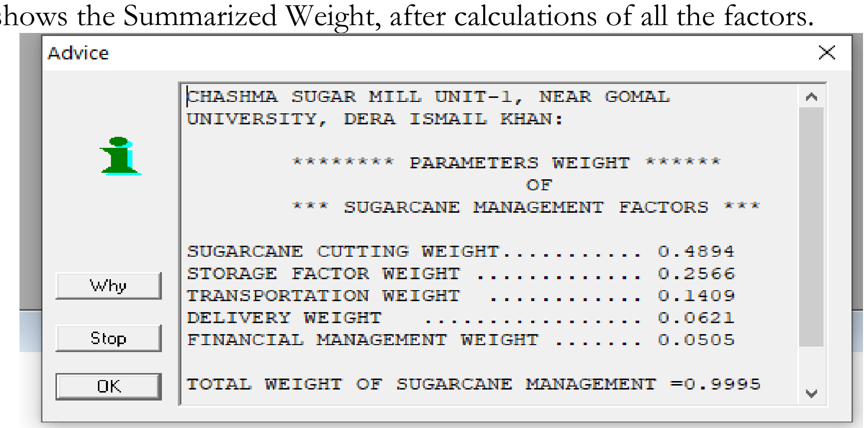

Figure 16. Summarized Weight

Figure 17 represents the Final Advice of the Sugarcane Management System.

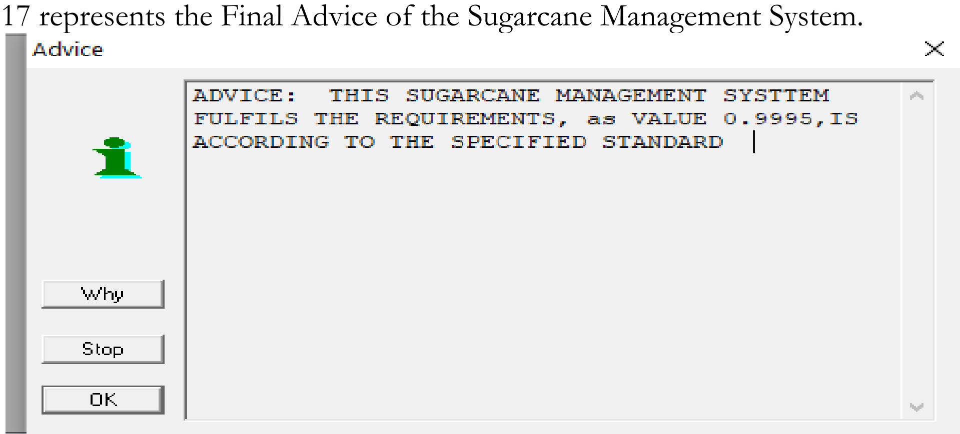

Figure 17. Final Advice on Sugarcane Management System

Conclusion:

We tried our best to achieve all of our objectives and results so as to integrate the real-world problem of Sugarcane Management System with various tools and technologies for the benefit of the farmers, mill owners, and all other stakeholders. This work will not only be financially beneficial but may also become a source of research for further studies in the future.

The gap in rough estimation of facts and figures without application of the modern useful techniques and technologies, we acquired the relevant knowledge through various sources, like; observation, interviews with domain experts, and literature studies. Factors of decision-making, along with required management functions, were identified through these sources. The acquired facts were analyzed through AHP, priorities and their importance were pointed out through their weights so as to make justified and rational decisions at each step of the solution of the problem. In this way, we were able to model the complete knowledge about the problem domain and presented through various diagrams and tables, Conceptual model, Tree diagram, Decision Table, etc. Every stakeholder and researcher can easily understand the complex decision-making system as well and can further utilize it for solving other similar problems.

The proposed model was tested for Chashma Sugar Mill Unit-1 Dera Ismail Khan as a Case Study through an ES named ESFSMS. This ES is a rule-based system and is based upon IF (Condition) THEN (Action). The same case is with the problem domain, which has conditions to be evaluated and consequences are judged. The proposed ESSMS can explain the problems with the justification of all decision-making processes. Similarly, the proposed ES for Sugarcane Management System can respond to questions like "Explain" and "Why".

In this way, both our goal and each one of our research objectives have been met with hope to fulfill the hope of fulfilling the requirements for the MS-CS degree.

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Author's Contribution: This is a part of the combined efforts during MS-CS thesis research work being supervised by Prof. Dr. Abdur Rashid Khan.

Conflict of interest. Not any

Project details: MS-CS thesis research work

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