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EVALUATION OF ENTERPRISES' QUALITY MANAGEMENT WITH INTEGRATED ANALYTICAL HIERARCHY PROCESS

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Abstract

The social requirements of quality are complex and high, not only for product performance, but also for life, reliability, ease of use, sanitation safety, environmental protection, and economy. These realistic conditions and environments need to be com-prehensively managed to all the factors that affect quality throughout enterprise management, such as product development, design, production, marketing, etc. Quality Management is an important business for enterprises to satisfy the ever-increasing demand of products, reduce costs, improve production and management activities and thus to increase competitiveness and sustainable development of production.

AHP (Analytical Hierarchy Process) is a comparative assessment method using human sense, which models the influence of the criteria associated with decision making into a hierarchical structure and chooses the best among alternatives. AHP is widely used in various fields of engineering, economy, society, management, education, medicine, etc. In this paper, we have considered how to evaluate enterprises' quality management objectively, intuitively and conven-iently using the Integrated Analytical Hierarchy Process (IAHP). First, a decision-making model was constructed using the IAHP developed in the Net-Oriented System Description Language (NSDL) environment, which combines the advantages of Petri Net and Object Oriented Programming Language. Compared with the previous AHP tools, the hierarchical structure model for the selection of the optimum alternative is built with Petri net diagrams to improve the intuition and convenience of tool. In addition, based on the built hierarchical model, situation enterprises' quality management was reasonably deter-mined.

Keywords: Enterprise, Quality Management, Integrated Analytical Hierarchy Process, Petri Net, Object-oriented Programming Language

Introduction

AHP is a decision-making tool, which models the influence of the criteria associated with decision making into a hierarchical structure and selects the best one among several alternatives, is widely used in various fields of economy, military, society, management, education, medicine, etc. In the past, AHP tools have been developed and used mainly in Excel software and in graphical user interface mode with the spreadsheet function. These tools include AHP Solver, XLSTAT, AHP Decision and Py-ahp calculator [1-5]. However, when the number of layers, criteria, and alternatives are large and the interaction is complex, the description of the structural and logical relationships of AHP tool takes a lot of time and effort and the intuition of the hierarchical structure model is lacking, and the users feel inconvenient. There are many software development tools that combine the advantages of Petri nets and object-oriented programming languages with good intuition and convenience in modeling in the world [6-11]. Hence, we developed IAHP in NSDL environment that was developed by combining the advantages of Petri nets and object-oriented programming languages. In IAHP, the hierarchical structure model is described by Petri net diagrams to enhance the intuition and convenience of the AHP tool. The characteristics of the proposed IAHP and other AHP tools are shown in Table 1. The type of large, high pressure, intermediate frequency induction hardening equipment includes horizontal work-piece movement, horizontal inductor movement, horizontal work-piece movement and horizontal inductor movement type, each of which has advantages and disadvantages. Therefore, the selection should be carefully considered.

Table 1: Comparison of AHP tools (✓ "supported", — "no support").

№	AHP tools	Modeling Language	AHP Structure Diagram Modeling	Qualitative Criteria	Quantitative Criteria
1	XLSTAT	Excel	—	✓	—
2	AHP Decision	Java	—	✓	—
3	AHPcalc	Excel	—	✓	—
4	AHP-jar	Java	—	✓	—
5	FuzzyAHP	R	—	✓	—
6	Ahp_Calculator	Python	—	✓	—
7	IAHP	NSDL	✓	✓	✓

2. Net-oriented System Description Language- NSDL

NSDL is a complex system modeling tool developed by combining the advantages of Petri nets and the object-oriented programming language VB based on Microsoft.NET Framework 4.0 library.

The formal definition of NSDL is as follows.

$$\text{NSDL} = [P, T, A, M, F, \theta, O] \quad (1)$$

P— set of places (includes integer, variable, real, stack, FIFO and equal place, in/out place terminal);

T— set of transitions (includes the GUI controls transitions), $P \cap T = \Phi$;

A— set of arcs (includes Flow, Reference and Inhibitor arc);

M— set of markings (includes the object tokens);

F— set of functional code of the element;

θ— set of attributes (delay time after firing, firing rate, priority, weight, capacity, type of elements, competition check and color, etc.);
O— set of user-defined objects modeled with NSDL's script;
S— set of sub-systems or sub-project models.
NSDL introduced elements including in/out place terminal, equal place, subsystem, model library management, code debugging and model compiling ability to further improve its flexibility, convenience, extensibility and productivity.

3. Evaluation of Enterprises' Quality Management with IAHP

3.1. Algorithm of Integrated Analytical Hierarchy Process

IAHP is the decision- making tool which integrates AHP structural model constructed by Petri net diagram with AHP analytical algorithm constructed by VB language of NSDL. The algorithm diagram of IAHP is as follows:

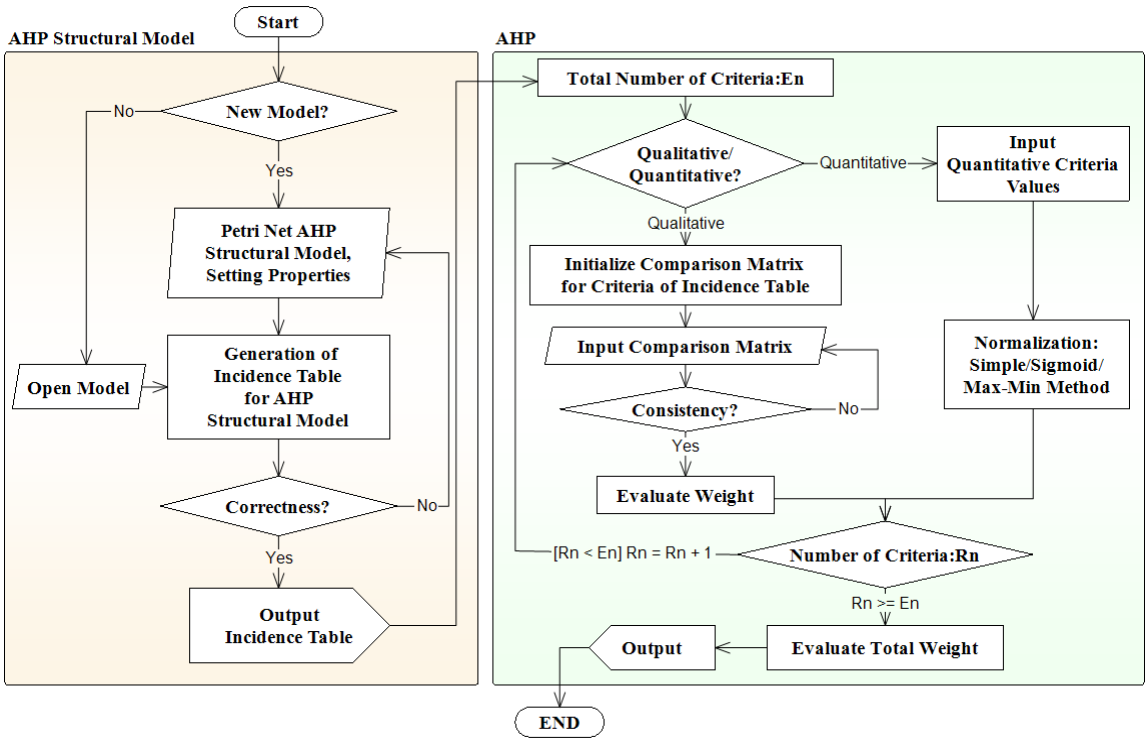


Figure 1 :Algorithm diagram of IAHP.

3.2. Evaluation of Enterprises' Quality Management

First, AHP structural model for decision-making problem should be constructed. As can be seen in Figure 2, for example, AHP structural model has 3 layers, 6 criteria and 4 alternatives.
The goal layer and criteria layer may be modeled with goal element (A1) and criterion element (B1～K1) in IAHP model library. These elements are transitions having Simplified input/output place. The alternative layer may be modeled as S1 or SFile. For example, AHP structural model can be constructed by connecting Simplified input /output place of each element as shown in Figure 2-4.

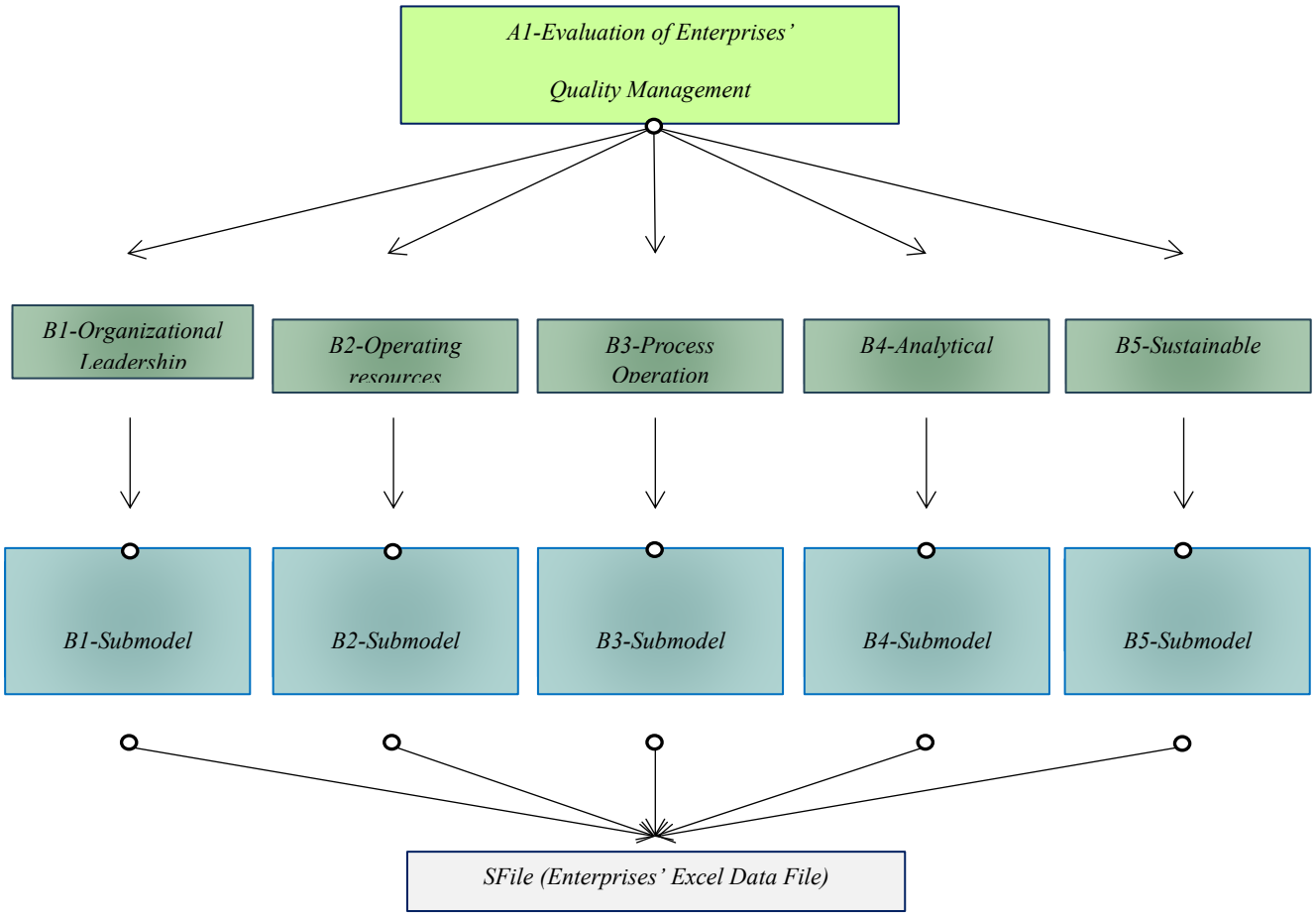


Figure 2: AHP structural model with SFile element.

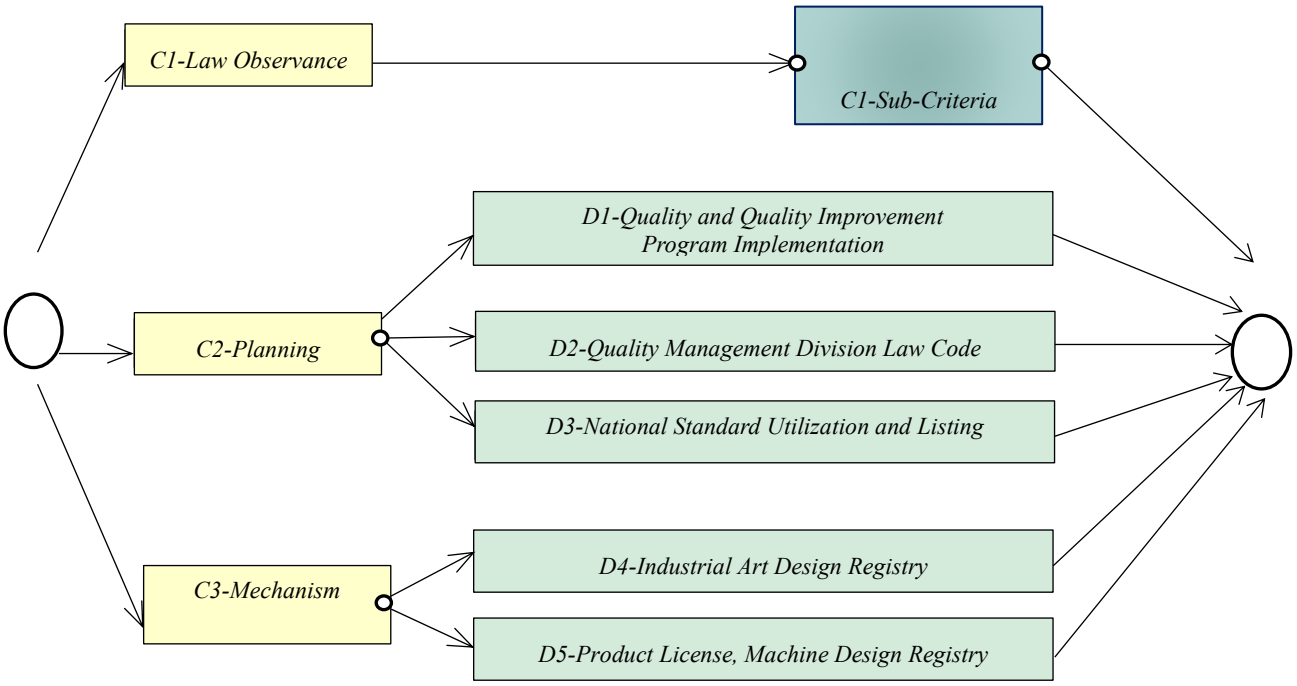


Figure 3: *Sub-model of Organizational Leadership (B1 criterion).*

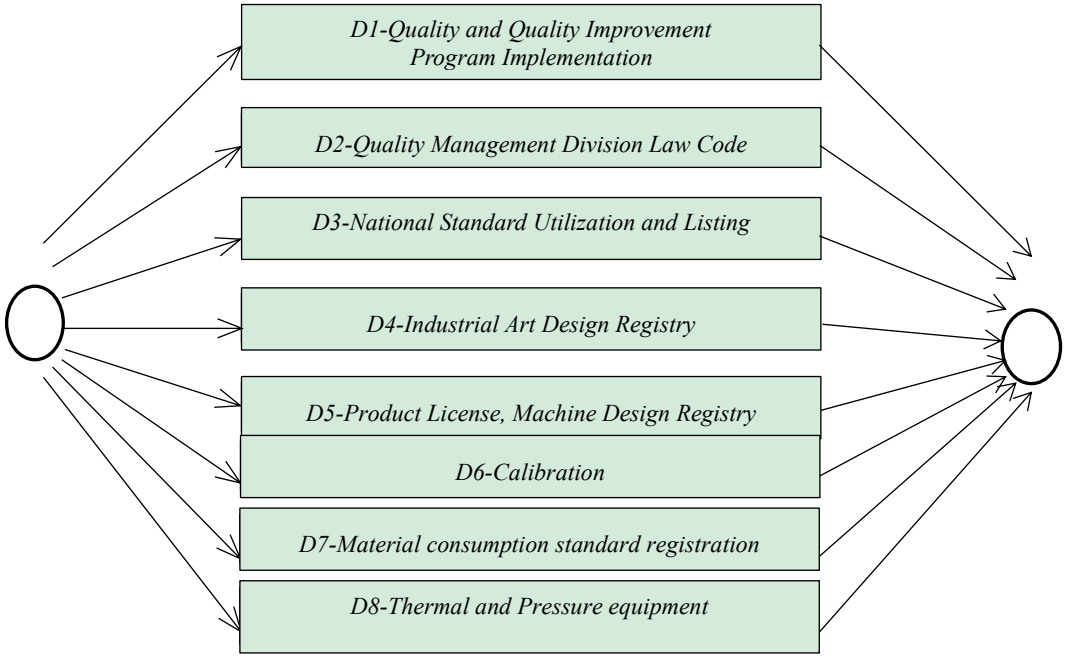


Figure 4. *Sub-model of Law Observance (C1- Sub-Criteria).*

The incidence table is generated from AHP structural model automatically as shown in Table 2.

Table 2: Incidence table generated from AHP structural model.

№	A1	B1	B2	B3	B4	B5	C1	C2	…	C19	C20	D1	D2	…	D97	D98
1	B1	C1	C4	C10	C14	C19	D1	D9	…	D93	D95	S1	S1	…	S1	S1
2	B2	C2	C5	C11	C15	C20	D2	D10	…	D94	D96	S2	S2	…	S2	S2
3	B3	C3	C6	C12	C16		D3	D11	…		D97	S3	S3	…	S3	S3
4	B4		C7	C13	C17		D4		…		D98	S4	S4	…	S4	S4
5	B5		C8		C18		D5		…			S5	S5	…	S5	S5
6			C9				D6		…			S6	S6	…	S6	S6
7							D7		…			S7	S7	…	S7	S7
8							D8		…			S8	S8	…	S8	S8
…									…			…	…	…	…	…
98									…			S98	S98	…	S98	S98
99									…			S99	S99	…	S99	S99
100									…			S100	S100	…	S100	S100

Based on incidence table, the following AHP algorithm is constructed by VB language of NSDL.

Step 1: Judgment Matrix Construction When AHP diagram is constructed, judgment matrix to reflect expert's subjective assessment is made. The judgment matrix may be made by comparison table.

Table 3: Meaning of Comparison Values.

Comparison value	Meaning
1	Equally importance
3	Moderately importance
5	Strongly importance
7	Very strongly importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Step 2: Calculation of the weight by geometric average.

1) Calculate the product $M_i = \prod_{j=1}^{n} a_{ij}, i = \overline{1,n}$ of the elements of each row of judgment matrix A.
2) Calculate the n[th] square root $\overline{w}_i = \sqrt[n]{M_i}$ of M_i.
3) Calculate the weight by normalizing vector $\overline{W} = [\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n]^T$.

$$w_i = \frac{\overline{w}_i}{\sum_{j=1}^{n} \overline{w}_j} \quad (2)$$

Where, $W = [w_1, w_2, \ldots, w_n]^T$ is an eigenvector.

Step 3: Consistency

The validity of the judgment matrix is determined by the *CI* (Consistency Index).

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (3)$$

The consistency of the judgment matrix is determined by the average random consistency ratio.

If CI doesn't satisfy the following condition, though it is less than 0.1, must check the judgment matrix again.

$$CR = \frac{CI}{RI} \le 0.1 \sim 0.15 \quad (4)$$

Table 4: Random Consistency Index.

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
R.I	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53

Comparative judgment matrices for qualitative criteria are made by experts. For example, Judgment matrix is shown in Table 5-9.

Table 5: Judgment matrix for goal A1.

A1	B1	B2	B3	B4	B5	Weight
B1	1	3	0.3333333	0.2	5	0.1295737
B2	0.3333333	1	0.2	0.1428571	3	0.063636
B3	3	5	1	0.3333333	7	0.2638338
B4	5	7	3	1	9	0.5100387
B5	0.2	0.3333333	0.1428571	0.1111111	1	0.0329178

Table 6: Judgment matrix for criterion B1.

B1	C1	C2	C3	Weight
C1	1	3	0.3333333	0.258285
C2	0.3333333	1	0.2	0.1047294
C3	3	5	1	0.6369856

Table 7: Judgment matrix for criterion B5.

B5	C19	C20	Weight
C19	1	3	0.75
C20	0.3333333	1	0.25

Table 8: Judgment matrix for criterion C1.

C1	D1	D2	D3	D4	D5	D6	D7	D8	Weight
D1	1	3	5	9	4	2	6	7	0.3276732
D2	0.3333333	1	3	7	2	0.5	4	5	0.1590827
D3	0.2	0.3333333	1	5	0.5	0.25	2	3	0.0721272
D4	0.1111111	0.1428571	0.2	1	0.1666667	0.125	0.25	0.3333333	0.0188806
D5	0.25	0.5	2	6	1	0.3333333	3	4	0.1073064
D6	0.5	2	4	8	3	1	5	6	0.2321565
D7	0.1666667	0.25	0.5	4	0.3333333	0.2	1	2	0.0488738
D8	0.1428571	0.2	0.3333333	3	0.25	0.1666667	0.5	1	0.0338995

Table 9: Judgment matrix for criterion C20.

C20	D95	D96	D97	D98	Weight
D95	1	0.1428571	0.3333333	0.2	0.0550225
D96	7	1	5	3	0.5638128
D97	3	0.2	1	0.3333333	0.1177864
D98	5	0.3333333	3	1	0.2633784

For quantification criteria, normalization can be performed by Simple, Max-Min and Sigmoid normalization method.

Table 10: Excel Data of Enterprises.

Evaluation Method - Qualitative Criterion: Input the integer mark 《Very High:100～86, High:85～76, Middle:75～66, Low:65～41, Very Low:40～0 》												
№	Item	D1	D2	D3	D4	D5	…	D17	D18	D19	D20	D21
1	Enterprise 1	50	55	55	52	40	…	28	2	88	77	66
2	Enterprise 2	52	75	30	88	66	…	58	28	28	19	13
3	Enterprise 3	99	31	89	98	90	…	2	78	1	44	69
…	…	…	…	…	…	…	…	…	…	…	…	…
98	Enterprise 98	19	17	22	28	87	…	79	70	89	74	31
99	Enterprise 99	61	19	94	90	29	…	75	47	26	66	9
100	Enterprise 100	44	28	56	46	97	…	74	6	40	69	31

For a given problem, let criteria be *K* layers and M_k criteria of the *k-th* layer denote $W_1^{(k)}, W_2^{(k)}, \cdots, W_{M_k}^{(k)}$.

Also, if the weight of the *j-th* criterion $W_j^{(k)}$ of the *k-th* layer is $w_{j^{(k)}}^{(k)}$, $\sum_{j^{(k)}=1}^{M_k} w_{j^{(k)}}^{(k)} = 1$.

Let the estimate of the alternative X_i for *j-th* criterion $W_j^{(1)}$ of the 1st layer (lowest layer) be $x_{j^{(1)}}$.

The overall estimate $\overline{x_i}$ of the alternative X_i is

$$\overline{x_i} = \sum_{j^{(k)}=1}^{M_k} \cdots \sum_{j^{(2)}}^{M_2} \sum_{j^{(1)}}^{M_1} w_{j^{(k)}}^{(k)}, \ldots w_{j^{(2)}}^{(2)} w_{j^{(1)}}^{(1)} x_{j^{(1)}} \quad (5)$$

The results are analyzed from the overall data. Analyzing by Table 10 data for 100 enterprises and Table 11 result, it is found that 77th enterprise is the best in quality management.

Table 11: Comprehensive Weight.

B Criterion Layer		**C Criterion Layer**		**D Criterion Layer**	
Criteria	**Weight**	**Criteria**	**Weight**	**Criteria**	**Weight**
B1- Organizational Leadership	0.129574	C1- Law observance	0.033467	D1- Implementation of Quality Improvement Program	0.010966
				D2- Documentation of Quality Management Laws	0.005324
				D3 - Utilization of National Standard and its registration	0.002414
				D4- Industrial Art Design Registration	0.000632
				D5 - Product License and Machine Design Registration	0.003591
				D6- Calibration	0.00777
				D7- Material consumption standard registration	0.001636
				D8- Technical inspection of thermal and internal air pressure equipment)	0.001135
		C2- Planning	0.01357	D9- The Establishment of QM General Direction and Quality Target	0.008644

				D10- Quality Management General Direction and Quality Targeting in accordance with NS10901	0.003 505
				D11- Implementation of February and July month for product quality improvement project	0.001 421
		C3- Mechanism System	0.082 537	D12- The appointment of quality control personnel(department) and making of functions of them	0.061 902
				D13- Forming the membership of quality control department according to the fixed number of personnel	0.020 634
B2- Operating resources	0.063 636	C4- Labor management	0.009 648	D14 – The number of employees/the fixed number of personal	0.000 193
				D15- The number of engineers, experts and employees	0.000 267
				D16 – The average grade of engineers and experts	0.001 565
				D17- The number of skilled workers above 4^{th}-grade /the total number of skilled workers	0.003 177
				D18- The average technical grade of skilled workers	0.002 264
				D19 - Process inspectors assigned to the enterprise leader or the technical department manager	0.000 736
				D20 -Average functional class for the specific occupation owned by process inspectors.	0.001 07
				D21 - Employees' monthly average salary (including additional rewards such as bonuses and subsidies).	0.000 377
		C5 - Technology Management	0.028 247	D22- QM Learning Resources	0.000 825
				D23 - Quarterly Technical Learning of Quality Management	0.000 542
				D24 - Percentage of employees on the test.	0.000 825
				D25 - Mean test results of employees on the test.	0.001 825
				D26- Making of quality manual	0.003 804
				D27 - Process inspection regulations registered by a higher authority after the approval of the Quality Control Agency.	0.005 216
				D28- Process inspection regulations that reflect the objects, indices, a list of inspectors and means of inspection as specified in the quality control level assessment manual.	0.006 891
				D29 - Technical regulations and standard operating rules registered by higher authority	0.000 825
				D30 - Technical Regulations and Standard Operations Regulations in line with Current Production Processes	0.001 252

				D31- QM Information System Logging and Data Input	0.000 381
				D32- Usage of Quality Management Technique	0.002 66
				D33- Information Level Assessment	0.002 66
				D34- The Title of Model Technical Innovation Unit	0.000 542
		C6- Equipment management	0.006 376	D35- 26th Model Machine Prize (including Machines, Workshops and Enterprises)	0.001 594
				D36 - Modernization class	0.000 956
		C7- Materials Management	0.001 695	D37 – The ratio of localization for raw and other materials	0.000 2
				D38- Implementation of monthly plans for procurement of raw materials and materials	9.33E-05
				D39 - Quality assurance documentation of raw materials and materials.	0.000 446
				D40 - Documentation for ability assessment of suppliers (major raw and material procurement units)	0.001 106
		C8- Measuring Measuring Management	0.003 141	D41 - The analysis room (laboratory, laboratory) built	0.000 766
				D42 - Standard Analytical Laboratory Test Environments	0.000 341
				D43 - The percentage of quality index that is normally analyzed among the number of finished product quality indices.	0.000 23
				D44 - The number of quality indices that can be analyzed among the number of important quality indices of the raw material.	0.000 118
				D45 – The number of test instruments subjected to weighing tests/total number of test objects retained by the enterprise.	6.68E-05
				D46 - Quality Test	0.009 255
				D47 - The amount of inspection instruments currently available/the total amount of inspection tools that an organization must have	0.001 522
		C9- Financial Management	0.014 529	D48 - Technology Development Business Cost Investment Ratio	0.003 753
				D49 - Normalized Quality Cost Management	0.015 579
				D50 –Monthly (or quarterly) Analysis of Quality Cost	0.038 421
B3- Proces	0.263 834	C10- Developme	0.148 753	D51 - New product development planning and implementation	0.094 753

s Operation		nt and Design		D52 - Implementation of a Taguchi approach or QFD approach to new product development	0.015464
				D53 - Specifying tolerances in engineering process design	0.000856
		C11-Production Process	0.069488	D54 - Product certification	0.001808
				D55- Regular analysis records of raw materials, semi-finished goods and finished products in the analysis room.	0.002704
				D56-The inspector's process inspection log which records process inspection in accordance with the form specified in the process inspection regulations is recorded correctly in the process inspection log.	0.001221
				D57 - The process inspection marking method for critical raw materials, semi-finished products and finished products, and the implementation.	0.005694
				D58 - Submitting a test database and test log database file for analysis, process inspection data	0.002704
				D59-QM process planning	0.001221
				D60 - Reflecting the important factors of the production process that affect the quality fluctuations of finished products (semi-finished products) in the QM process chart.	0.005694
				D61 - Systematic recording of the values of the important factors of the production process reflected in the QM process chart.	0.008286
				D62 - Building an Excel Production Process Database that can be considered to relate the key factors of the production process and the quality indices of the finished product.	0.011627
				D63 - The normative process of non-compliant product tracking management	0.002704
				D64 - Can the enterprise identify and track the worker, inspector, and critical equipment in a process for any major product produced or shipped by the enterprise?	0.001221
				D65 - Can you track the purchasing units, dates of entry and exit, and the status of acceptance and rejection of any raw and other materials used in the production of the product?	0.008286
				D66 - The application of a control chart to the main quality characteristics of the main product or to the important factors of the production process.	0.004143
				D67 - Application of Extraction Testing to National Standard for Main Products and semi-finished products.	0.000935
		C12-	0.031076	D68-Regulatory work for quality assurance including damage compensation, product	0.001369

		Sales Service		replacement, product repair and post-marketing service.	
				D69-Quality assurance project, quality assurance period and issuing quality assurance certificate.	0.002 041
				D70 – The record of accepting complaints and opinions of customers and taking actions in the customer's complaint handling register	0.008 018
				D71 - The normative process of customer satisfaction research	0.014 569
				D72 - Customer satisfaction assessment with customer satisfaction assessment index more than once per year.	0.001 52
				D73-Customer satisfaction index	0.003 749
		C13-Beef application	0.014 517	D74-The Regulations on Quality-related Prizes and Penalties of Daily Production and Finance Review and Regular Execution of them	0.009 247
				D75 - Regular reviewing quality in the review of production schedule performance.	0.014 314
				D76 – Quality award for technicians and skilled workers who contributed to new product development and quality improvement	0.068 515
B4-Analytical Evaluation	0.510 039	C14-Process Capacity Analysis	0.260 139	D77 - The calculated rejection rate (%) for the main products in the inspection record database, in the process inspection and quality control agency product inspection.	0.100 924
				D78 - The percentage rejection of semi-finished, important raw and other materials by process in the inspection log database (%) calculated.	0.033 641
				D79-The calculated process capacity index (*Cp*) for major semi-finished products (or important factors) by process.	0.010 695
				D80 - Average Process Capacity Index (*Cp*) of Main Products	0.004 336
		C15-Cause analysis for rejected products	0.134 565	D81 - Analysis of the causes of malfunction of finished products on a monthly basis.	0.001 758
				D82-Analysis of the causes of malfunction of major semi-finished products by month	0.001 786
		C16-Internal Review	0.016 789	D83 - The internal audit of quality management systems conducted more than once a year	0.003 823
				D84 - The quality management system internal audit report	0.008 548
				D85 - Internal Judges' term of Review	0.018 3

		C17-Competitive Enterprise Related Data	0.032 457	D86 - Competitive business inventory and product image data	0.042 097
				D87 - Quality characteristics and price comparison evaluation with homogeneous products produced by competitive enterprises more than once a year.	0.006 921
				D88 - Is the main product of an enterprise best in terms of price and quality than the homogeneous product produced by domestic competitors?	0.017 069
				D89 - Is the main products of an enterprise superior in terms of price and quality to those of the homogeneous products produced by international competitors?	0.018 516
		C18-Basic Product Assessment	0.066 088	D90 - Ten Best Business Evaluations in the last three years	0.006 172
				D91-The registration of international patent and registration of origin designation of major products in the last three years.	0.000 453
				D92 - Quality certification of major products for the last three years, February 2 products and December 15 quality medals	0.004 64
B5-Sustainable Development	0.032 918	C19-Quality Improvement	0.024 688	D93 - Annual increase in the acceptability of major products in the last three years.	0.000 969
				D94 - Annual increase in the process capacity index of major products over the last three years	0.002 167
		C20-Management Resource Improvement	0.008 229	D95 - Annual increase in the rate of engineers and specialists among employees over the last three years.	0.010 966
				D96 - Annual increase in the rate of skilled workers of grade 4 or above in the last three years.	0.005 324
				D97 - Annual reduction in quality costs in the last three years	0.002 414
				D98- The annual increase in modernized and CNC-based equipment in production processes including packaging of products over the last three years.	0.000 632

4. Conclusion

In this paper, we have considered how to evaluate enterprises' quality management objectively, intuitively and conveniently using the Integrated Analytical Hierarchy Process (IAHP). In the IAHP tool proposed, the hierarchical structure model can be constructed in Petri nets diagram in NSDL environment to improve the intuition and convenience of modeling.

Abbreviations

IAHP:	**Integrated Analytical Hierarchy Process**
NSDL:	Net-oriented System Description Language
GUI:	Graphical User Interface
FIFO:	First-In First-Out

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Conflicts of Interest
The authors declare no conflicts of interest.

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