AN AHP-WEIGHTED COMPLEX RISK INDEX FOR INTEGRATED MANAGEMENT SYSTEM PROCESSES IN AUTOMOTIVE COMPONENT MANUFACTURING

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DOI:https://doi.org/10.5281/zenodo.24145392

Abstract. Automotive component suppliers are required to comply simultaneously with IATF 16949, ISO 14001 and ISO 45001, yet quality, environmental and occupational health and safety (OH&S) risks are usually assessed in separate registers using different scales. This paper proposes a Complex Risk Index (KRI) that adds a fourth criterion – cross-domain interdependence (I) – to the classical FMEA criteria of severity (S), occurrence (O) and detection (D), with the criterion weights derived by the Analytic Hierarchy Process (AHP). The model was tested on 13 real process risks of an automotive component manufacturer. The resulting ranking differs substantially from the Risk Priority Number (RPN) for high-severity, low-probability risks and remains stable under sensitivity and Monte Carlo analysis.

Keywords: integrated management system, risk assessment, FMEA, AHP, complex risk index, IATF 16949, ISO 14001, ISO 45001.

Introduction

The automotive industry is one of the priority sectors of the economy of Uzbekistan, and the competitiveness of local component suppliers depends to a large extent on their ability to meet the requirements of international management system standards. For a component supplier, certification to IATF 16949 is a precondition for entering global supply chains, while ISO 14001 and ISO 45001 are increasingly demanded by vehicle manufacturers. Empirical research shows that IATF 16949 adds value to ISO 9001 mainly through stricter process control and risk-based thinking [1].

Implementing these standards as separate systems leads to duplicated documentation, audits and risk registers. Integration of management systems is therefore widely discussed in the literature: the elements and functions that can be integrated have been identified [2], and the guiding principles of integrated management systems (IMS) have been formulated [3]. A model for integrating automotive quality management requirements has also been proposed [4]. Nevertheless, risk assessment within an IMS usually remains domain-specific. The Risk Priority Number (RPN = S×O×D) of the FMEA methodology [5] evaluates each failure mode in isolation and does not reflect how an event in one domain may propagate to another. Combined treatment of safety, environmental and quality risks with FMEA has been shown to be feasible in project management [6], and AHP-based approaches are actively used for multi-criteria decision-making in the automotive industry [7]. However, a single indicator that ranks quality, environmental and OH&S risks of IMS processes while accounting for their interdependence has not been proposed.

The aim of this study is to develop and test a Complex Risk Index that provides a single comparable assessment of IMS process risks at automotive component suppliers and takes into account cross-domain interdependence.

Materials and methods

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In this study a risk is understood as the possibility that an IMS process fails to achieve its objective (KPI). The model is applied in seven steps: (1) forming an integrated risk register; (2) determining criterion weights by AHP; (3) scoring S, O and D; (4) determining cross-domain interdependence; (5) calculating KRI; (6) classifying risks; (7) decision-making and corrective actions. For each risk k, the index is calculated as a weighted sum of four criteria scored on a 1–10 scale:

$$KRI_k = w_S \cdot S_k + w_O \cdot O_k + w_D \cdot D_k + w_I \cdot I_k, \quad (1)$$

where w_S, w_O, w_D and w_I are the AHP weights ($\Sigma w = 1$). The interdependence score of domain d is derived from an expert interaction matrix $\Phi = [\varphi_{dj}]$ between the quality (Q), environmental (E) and OH&S (S) domains:

$$I_d = 1 + 9 \cdot (\Sigma_{j \neq d}\, \varphi_{dj}) / (n - 1), \quad n = 3, \quad (2)$$

where $\varphi_{dj} \in [0; 1]$ expresses the extent to which an event in domain d affects domain j. Unlike the multiplicative RPN, the additive form of (1) does not allow a low occurrence score to suppress a high severity score.

The integrated register included 13 risks of Enterprise A, an automotive component manufacturer: four quality risks (r1, r2, r8, r9), four environmental risks (r3, r4, r10, r11) and five OH&S risks (r5, r6, r7, r12, r13), each linked to a specific operation and to the corresponding organizational standard. Criterion weights were obtained by AHP [8] from a consensus pairwise comparison matrix built by a four-member expert team (quality, environmental, OH&S and internal audit specialists with 5–15 years of experience). The S and O values for OH&S and environmental risks were taken from the enterprise's hazard matrix and environmental aspects register and rescaled from 1–5 to 1–10; D values and the S and O values of quality risks were assigned by expert consensus in line with the AIAG & VDA FMEA methodology [5]. Robustness was tested by a one-at-a-time sensitivity analysis (10 weight variants) and a 10,000-run Monte Carlo simulation [9].

Results

The pairwise comparison matrix and the resulting weights are given in Table 1. The consistency ratio CR = 0.0103/0.90 = 0.011 < 0.10 confirms the logical consistency of expert judgements [8]. The weights calculated by column normalization, the geometric mean and the principal eigenvector differed by no more than 0.0015.

Table 1. Pairwise comparison matrix and AHP weights of the criteria

Criterion	S	O	D	I	Weight
S (severity)	1	2	3	4	0.466
O (occurrence)	1/2	1	2	3	0.277
D (detection)	1/3	1/2	1	2	0.161
I (interdependence)	1/4	1/3	1/2	1	0.096

$\lambda_{max} = 4.031$; CI = 0.0103; RI = 0.90; CR = 0.011

The interaction matrix agreed by the experts ($\varphi_{QE} = 0.3$, $\varphi_{QS} = 0.2$, $\varphi_{EQ} = 0.1$, $\varphi_{ES} = 0.6$, $\varphi_{SQ} = 0.1$, $\varphi_{SE} = 0.2$) gave $I_Q = 3$, $I_E = 4$ and $I_S = 2$. The environmental domain thus has the highest potential to spread to other domains: for example, volatile organic compound emissions in the painting shop directly affect worker health.

Table 2 compares the KRI ranking of the leading risks with the RPN ranking. The highest KRI values were obtained for metal forming (r6, KRI = 6.16) and drilling operations (r5, KRI = 5.99). The average KRI by domain was 5.54 for OH&S, 5.14 for quality and 4.58 for environment.

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Table 2. Comparison of RPN and KRI rankings (selected risks)

Code	Operation	Domain	RPN (rank)	KRI (rank)	Shift
r6	Part forming	S	224 (1)	6.16 (1)	0
r5	Drilling of parts	S	192 (2)	5.99 (2)	0
r11	Storage of paint materials	E	96 (10)	5.63 (3)	+7
r12	Steel forming	S	112 (9)	5.60 (4)	+5
r8	Final product inspection	Q	180 (3)	5.44 (5)	−2
r1	Drying and moulding on injection press	Q	112 (8)	5.30 (6)	+2
r7	Mould loading on injection press	S	144 (4)	5.06 (7)	−3
r2	Painting process defects	Q	125 (5)	4.81 (11)	−6
r3	Plastic moulding fumes	E	48 (13)	3.84 (13)	0

For most risks the two methods give similar results, but two cases are decisive. Storage of paint materials (r11) moved from 10th place by RPN to 3rd by KRI (+7). First, in RPN the low occurrence (O = 2) sharply reduces the high severity (S = 8) through multiplication, whereas in KRI the criteria are added with weights. Second, the environmental domain has the highest interdependence (I = 4): a fire or explosion in paint storage causes environmental damage and may also injure workers. Conversely, painting process defects (r2) dropped from 5th to 11th place (−6) because of their relatively low severity (S = 5), which is penalized by the high weight of S.

In all 10 sensitivity variants (each weight changed by ±20% and w_I halved and doubled) r6 kept 1st place and r5 kept 2nd place; r11 and r12 exchanged 3rd and 4th places depending on the weights. In the Monte Carlo simulation with simultaneous random variation of all weights within ±20%, r6 remained first in 100% of runs. When, in addition, the S, O and D scores of every risk were randomly changed by −1, 0 or +1 point, r6 remained in the top three in about 81% of runs.

Discussion

No risk reached the “high” level (KRI ≥ 7), which indicates that existing controls keep risks at a medium level. At the same time, the model made it possible to target improvement measures. For r6 the current control relies only on work instructions (an organizational barrier), so a sensor interlock or automatic stop (Poka-Yoke, an engineering barrier) was recommended; for r11 an automatic gas detection alarm was recommended, which also creates a formal link between the environmental aspects procedure and the hazard matrix. Risks r12 and r8 were set as priority objects of the next internal audit cycle.

The model has limitations. The difference between neighbouring risks is small (0.17 between r6 and r5), so KRI results should be interpreted as priority groups rather than exact ranks. In the present approbation I is defined at domain level, so its effect on KRI is limited (up to 0.19 points) and appears mainly when risks of different domains are compared. Determining φ coefficients for each individual risk

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is a direction for further research. Compared with integral IMS performance indicators [10], the KRI is designed not to measure the overall result of the system, but to prioritize individual process risks for audit and corrective action.

Conclusion

The proposed Complex Risk Index allows quality, environmental and OH&S risks of IMS processes to be assessed with a single comparable indicator. Adding the cross-domain interdependence criterion and AHP-based weights makes the model identify high-severity, low-probability risks earlier than RPN and take into account their potential to spread across domains. The results of the approbation at an automotive component manufacturer were used to set internal audit priorities and preventive measures. Criterion weights and interaction coefficients are expert-based and should be re-estimated when the model is transferred to another enterprise.

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