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Sustainable supplier selection problem using FMEA and fuzzy MOORA

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Abstract

Sustainable supply chain management (SSCM) has become one of the important subjects in the industry and academia in the recent years. Supplier selection, as a strategic decision, plays a significant role in SSCM. Researchers proposed different multi criteria decision making (MCDM) methods to evaluate and select sustainable suppliers. In the previous studies, desirable features of a supplier was the main factor for supplier evaluation and risk factors hase been neglected. Therefore, the current research uses failure mode and effects analysis (FMEA) as a risk analysis technique to consider the supplier's risk in combination with an MCDM method. Finally, to demonstrate the effectiveness of the proposed approach a case study and sensitivity analysis is performed.

Keywords:
Supplier selection, Sustainability, Fuzzy MOORA, FMEA.

1. Introduction

Supplier selection is an important operational and strategic task to have a sustainable supply chain (Sarkis & Dhavale, 2015). Supplier selection is a process to order optimum quantities from the best supplier with the right price and quality at the right time (Ayhan & Kilic, 2015). It is important because having a huge effect on the strategic and operational performance of the organization. Furthermore, selecting right suppliers cause reducing production and inventory cost, improvement of quality, flexibility and satisfaction customer expectations (Çebi & Otay, 2016). Because of the government force and the profit advantages, most of the firms deliberated the environmental criteria along with the economic calculations. In addition, there is another notion named as the sustainable supply chain that considers the economic, environmental and social criteria simultaneously. Table 1 shows the definition of the sustainability in different studies.

Table 1- Sustainability definition

Researcher	Definition
(Carter & Rogers, 2008)	Integration of economic, social and environmental problems.
(Özdemir, Härdtlein, Jenssen, Zech, & Eltrop, 2011)	Satisfy the needs of the current generation without limiting next generation.

To rank and select the best suppliers, researchers considered the sustainability of supplier as a positive score and used a multi criteria decision making method (MCDM) such as analytical hierarchy process (AHP) (Tam & Tummala, 2001), analytic network process (ANP), TOPSIS, fuzzy AHP. However, there are suppliers that have acceptable performance in sustainable factors, but they are faced with different risk in the real-world cases. For instance, consider a supplier that has the lowest cost in the daily tradeoffs. However, its cost raises 50 percent over the normal cost in some situation, because of the unstable supply chain. An MCDM method just considers the overall performance of a supplier and does not care to the risk of raising prices that may incur in some situations. To have a widespread view on the supplier, it is essential to consider risks beside the MCDM methods. One of the well-known techniques for risk analysis is failure mode and effect analysis (FMEA).

Failure mode and effect analysis developed for the military goals in the 1950s. Also, it used as a part of six sigma methodology in the industry (Raisinghani, Ette, Pierce, Cannon, & Daripaly, 2005) and (Li & Zeng, 2014).

2. Methods

The procedure for ranking and evaluating a supplier in the current paper contains two main stages. In the first part, the score and rank of each supplier is obtained by the fuzzy MOORA as an MCDM method. After that, FMEA technique was used to assess the amount of risk for suppliers. Finally, both results are integrated to get a reliable rank for different suppliers.

2.1 Fuzzy multi-objective optimization on the basis of ratio analysis (Fuzzy MOORA)

The main reasons for application of fuzzy MOORA instead of the rest of well-known MCDM methods are:

1. MOORA is the newest MCDM method that was constructed already knowing weak aspects of the older methods.
2. MOORA requires minimal setup time and has a stable nature as the literature indicates.

The steps of fuzzy MOORA with ration approach can be enumerated as (Akkaya, Turanoğlu, & Öztaş, 2015):

Step 1: By using a triangular fuzzy number prepares decision matrix which *m* is the number of alternatives and *n* is the number of criteria:

$$\tilde{X} = \begin{bmatrix} [x_{11}^l, x_{11}^m, x_{11}^u] & [x_{12}^l, x_{12}^m, x_{12}^u] & \dots & [x_{1n}^l, x_{1n}^m, x_{1n}^u] \\ \dots & \dots & \dots & \dots \\ [x_{m1}^l, x_{m1}^m, x_{m1}^u] & [x_{m2}^l, x_{m2}^m, x_{m2}^u] & \dots & [x_{mn}^l, x_{mn}^m, x_{mn}^u] \end{bmatrix}$$

Step 2: Decision matrix in pervious step should be normalized. This process can be done using the method introduced by (Baležentis, Baležentis, & Brauers, 2012).

$$x_{ij}^{l*} = \frac{x_{ij}^l}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (1)$$

$$x_{ij}^{m*} = \frac{x_{ij}^m}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (2)$$

$$x_{ij}^{u*} = \frac{x_{ij}^u}{\sqrt{\sum_{i=1}^{m}\left[\left(x_{ij}^l\right)^2 + \left(x_{ij}^m\right)^2 + \left(x_{ij}^u\right)^2\right]}} \quad (3)$$

Step 3: Weighted normalized decision matrix by multiplying criteria weight w_j in the normalized decision matrix.

$$V_{ij}^u = w_j x_{ij}^{u*}$$

$$V_{ij}^m = w_j x_{ij}^{m*}$$

$$V_{ij}^l = w_j x_{ij}^{l*}$$

Step 4: The following formula should calculate this step performance of normalized value:

$$\bar{y}_i = \tilde{V}_{ij}^{\;+} - \tilde{V}_{ij}^{\;-} \quad (4)$$

which $\tilde{V}_{ij}^{\;+}$ is performance value of positive criteria and $\tilde{V}_{ij}^{\;-}$ is performance value of negative criteria.

Step 5: To change the normalized fuzzy performance value as a non fuzzy value, this study is used the following equation named As the best non fuzzy performance (BPN):

$$BPN_i\left(y_i\right) = \frac{\left(y_i^u - y_i^l\right) + \left(y_i^m - y_i^l\right)}{3} + y_i^l \quad (5)$$

where $\tilde{y}_i = \left(y_i^l, y_i^m, y_i^u\right)$

After implementation of the above BPN formula, the supplier can be ranked by sorting from the largest value to the smallest. The best one is biggest.

2.2 Failure mode and effects analysis (FMEA)

Determination of risk criteria is the first step for evaluation supplier's risk. By using company's historical data and review previous studies, expert team can select significant risk criteria. For the implementation of FMEA, we should examine three aspects of risks, namely: severity, occurrence and detection then design FMEA scheme for all of the criteria. Base on the (Carlson, 2012), this paper uses 1-10 point scale to design the scheme. Table 2 is a general form of the scheme that has been applied in various cases (Li & Zeng, 2014).

Table 2- General evaluation scheme

Rank	Severity	Occurrence	Detection
9-10	Failure to meet safety and/or regulatory requirements	Very high and inevitable	No detection chance
7-8	Loss or degradation of primary function	High and uncertain	Probably detected by offline testing
5-6	Loss or degradation of secondary function	Moderate	Probably detected by online planned testing
2-4	Annoying effect	Low	Probably detected by online continuous testing
1	No discernible effect	Very low	Highly visible

After designing scheme its turn to decision makers and expert team to select ranks of criteria in severity, occurrence, and detection.

Reform FMEA scheme to mathematical

RPN concept is a method which convert the FMEA scheme results to a mathematical number. Assume *S*, *O* and *D* is ranking number for severity, occurrence and detection, respectively. One of the simplest and oldest formula for *RPN* is multiplying *S*, *O* and *D*. But this formula has a lot of weakness. (Li & Zeng, 2014) enhanced *RPN* formula as follows:

They define *L* as a risk number that is multiplied *S* and *O*. So $L=S*O$

Also, they define risk percent as follows:

$$R=\frac{(L-1)*100}{99} \quad (6)$$

But up to eqation (6), the point detection has no role in this formula. Therefore they define ep = -0.1*D+1.55 and introduced the final *RPN* as:

$$R=\left(\frac{(L-1)}{99}\right)^{ep}*100 \quad (7)$$

Justification of *ep* formula is that because detection scale is between 1 to 10. So, when detection is in the middle or 5.5 the influence of detection on the total risk should be none. So, when detection is 5.5 *ep* is equal to 1 and have no effect on *R*.

Finally, risk discount that is useful for assessing supplier can be obtained by multiplying the risk from FMEA and score from MOORA by the following formula:

Risk discount= MOORA*(1-risk) (8)

Fuzzy MOORA result has a positive aspect and risk is negative. Hence, multiple directly is not reasonable, and it is necessary to reform one of them. So, Equation (8) is used to integrate the result of fuzzy MOORA and FMEA.

3. Case study

The effectiveness of the proposed model is discussed through a case study in Tehran, Iran. The company produces various types of colors such as plastic paint, bright oil color, swimming pool paint, spray paint. The current sourcing strategy is based on the manager's judgment and previews on the purchase history that is not a scientific and sustainable approach. There are different types of raw material required for production such as Resin, Titanium, Calcium carbonate, and Zinc oxide. For a brief, this paper applies supplier selection for main raw material name Resin. So, we should examine 12 suppliers that can supply Resin.

Due to saving business privacy of manufacturer and supplier, instead of using the special name of companies this paper uses symbol names such as s1, s2, .. as a supplier's name. Determination of important criteria according to the case is the first step for selecting sustainable suppliers. So a meeting was performed consisting of the company's experts, and the result is in follows:

Economic

Cost: Supply requirement of raw material causes different costs like purchasing cost, holding cost and ordering cost.

Quality: This criterion shows a supplier's ability to control service and product quality.

Delivery: This criterion is to assess transporting speed of suppliers.

Environmental

Environmental management system (EMS): Certifications such as ISO 14000.

Chemical leakage: Since most of the raw material require for production is chemical, so the risk of chemical leakage is necessary to consider.

Pollution: The chemical wastes cause further pollution of the environment.

Social

Worker dismissal: Shows the number of fired worker.

Worker safety: Criterion for analysis worker injuries.

Training, education and community development: Effective factors in this criterion can be the number of created jobs, average hours of training per year per employee for the manager and personal (Azadnia, Saman, & Wong, 2015).

The interests and rights of employee: The real implementation of workers' interests and rights.

3.1 Application of fuzzy MOORA

According to expert's opinion, effective criteria for evaluating supplier by the fuzzy MOORA method are the cost, quality, delivery, EMS, pollution, worker safety and the interests and rights of employees.

After criteria selection, by using questionnaires, the expert judgment will be collected. Next step, experts judgment change to a fuzzy number using linguistic scale prepared by (Awasthi, Chauhan, & Goyal, 2010).

Table 3- Linguistic terms for alternatives ratings

Linguistic term	Membership function
Very poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,9)

Decision matrix based on linguistic terms of Table 3 is prepared in Table 4. Based on the fuzzy MOORA method, decision matrix in Table 4 should be normalized and result in multiply in weight of the criteria. Criteria weights according to Table 4 are 0.16, 0.2, 0.13, 0.12, 0.14, 0.13 and 0.12 respectively. For example, weight for cost is 0.16 and for quality is 0.2.

According to the nature of the criteria, the amount of $\overline{y}_i$ is calculated by using Equation (4) and the result is illustrated in the first three columns of Table 5. However, they are fuzzy number that is not compatible to use for comparison and ranking, so Equation (5) is used to reform fuzzy as a single number, and the result is shown in the fourth column.

Table 4- Decision matrix

	cost	quality	delivery	EMS	pollution	Worker safety	Interests and rights of the employee
S1	(1,3,5)	(7,9,9)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)
S2	(1,1,3)	(7,9,9)	(1,1,3)	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)
S3	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)
S4	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(1,1,3)	(1,3,5)	(7,9,9)
S5	(3,5,7)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)
S6	(1,1,3)	(1,1,3)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)
S7	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,9)	(7,9,9)
S8	(1,1,3)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)
S9	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(1,1,3)
S10	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)
S11	(3,5,7)	(5,7,9)	(1,3,5)	(1,3,5)	(1,3,5)	(1,1,3)	(1,3,5)
S12	(7,9,9,)	(1,1,3)	(1,3,5)	(1,3,5)	(7,9,9)	(3,5,7)	(1,3,5)

Table 5- Fuzzy score of suppliers

	y_i^l	y_i^m	y_i^u	Score	Rank
S1	0/124	0/176	0/269	0/192	7
S2	0/125	0/177	0/242	0/182	9
S3	0/106	0/191	0/271	0/192	8
S4	0/126	0/194	0/265	0/190	5
S5	0/140	0/220	0/299	0/219	2
S6	0/061	0/111	0/204	0/126	12
S7	0/193	0/272	0/334	0/265	1
S8	0/069	0/133	0/213	0/141	11
S9	0/132	0/203	0/283	0/209	4
S10	0/137	0/216	0/296	0/214	3
S11	0/082	0/152	0/232	0/153	10
S12	0/129	0/195	0/248	0/192	6

3.2 Application of FMEA

According to expert's opinion, effective risk criteria for current case study are cost, quality, delivery, Chemical leakage, worker safety and worker dismissal.
To evaluate total risks, we should design FMEA scheme contain severity, occurrence, and detection for every criterion. FMEA scheme for cost is given in Table 6. Furthermore scheme for rest of criteria is provided in the appendix.
After scheme preparation, the computing part of FMEA must be implemented. For the cost, decision makers express that S1 has 4 % more than market price, about 8% happen during time horizon and the ability to predict the exact amount fluctuates from one period.

Table 6- FMEA scheme for cost

Rank	Severity	Occurrence	detection
10	More than 11 % above the market price	About 15% happen per period	No chance to detect
8-9	8 % more than market price	More than 10% per period	The ability to predict the occurrence a week ago
6-7	5 % more than market price	About 8% happen during time horizon	The ability to predict the exact amount fluctuates from a week ago
4-5	4 % more than market price	About 6% happen during time horizon	The ability to predict the occurrence of fluctuations in a prior period
2-3	2 % more than market price	About 4% happen during time horizon	The ability to predict the exact amount fluctuates from one period
1	Equal to market price	Always equal to market price	Quite predictable before scheduling

Table 7- Expert's judgment for risk criteria

	Cost			quality			delivery			Chemical leakage			Worker safety			Worker dismissal		
	S*	O*	D*	S	O	D	S	O	D	S	O	D	S	O	D	S	O	D
S1	۴	۶	۲	۳	۳	۶	۲	۵	۶	۶	۳	۶	۲	۱	۵	۳	۱	۲
S2	۳	۳	۳	۵	۶	۶	۵	۳	۴	۶	۵	۶	۲	۳	۱	۲	۱	۱
S3	۱	۲	۵	۵	۵	۸	۵	۴	۲	۲	۶	۴	۲	۲	۴	۱	۵	۱
S4	۳	۴	۴	۱	۳	۳	۲	۳	۳	۱	۱	۵	۱	۲	۳	۲	۳	۱
S5	2	۵	۱	۲	۲	۲	۳	۴	۵	۳	۵	۷	۱	۲	۹	۳	۱	۹
S6	۲	۵	۳	۲	۳	۷	۲	۱	۶	۳	۵	۹	۱	۴	۷	۱	۲	۳
S7	۳	۵	۹	۴	۵	۸	۴	۳	۳	۵	۵	۵	۴	۵	۸	۳	۵	۷
S8	۳	۶	۳	۳	۶	۶	۲	۵	۸	۱	۵	۹	۳	۵	۷	۲	۴	۵
S9	۲	۴	۶	۳	۵	۷	۳	۶	۹	۶	۲	۳	۲	۶	۷	۱	۵	۸
S10	۳	۲	۲	۶	۹	۸	۴	۷	۹	۵	۲	۸	۱	۳	۵	۳	۶	۹
S11	۱	۳	۱	۲	۳	۵	۵	۲	۲	۳	۳	۴	۲	۲	۵	۲	۳	۶
S12	۲	۲	۲	۳	۴	۶	۱	۵	۲	۱	۲	۳	۴	۳	۶	۲	۵	۶

S: severity, O: occurrence, D: detection

Thus, Table 7 shows that cost ranks for s1-rasin are 4, 6 and 2 in severity, occurrence, and detection, respectively. From the formulations in the previous section, L = 24 and ep = 1.35, so as a result, the risk of S1 for the cost is equal to d = 13.9 %. In the same way, the amount of the risk obtained for the rest of the criteria.

Table 7 shows expert judgment for risk criteria. As it is clear, every criterion has three parts: severity, occurrence, and detection. To obtain total risk three steps remain:

Firstly, by using *RPN* formula in the previous section get the amount of unweight risk.

Secondly, multiply the amount of unweight risk to criteria's weight to have realistic output because different criteria do not have the same importance.

Third, Using weighted average to get scalar the amount of risk. The weighted average formula is in below which W_i is a weight for *i-th* criteria and d_i is the amount of risk in *i-th* criteria.

Criteria weight are 0.2, 0.18, 0.15, 0.19, 0.15 and 0.13 for cost, quality, delivery, chemical leakage, worker safety and worker dismissal, respectively.

$$\text{Total Risk} = \frac{\sum_{i=1}^{6} W_i d_i}{\sum_{i=1}^{6} W_i}$$

Finally, Table 8 is the final result for the supplier risk for each item.

4. Results and sensitivity analysis

After all, the output from fuzzy MOORA should be multiplied in (1-FMEA) result to have a widespread judgment about suppliers. Table 9 shows the final result and final rank of every supplier.

Table 8- FMEA result

	FMEA	(1-FMEA)	RANK
S1	0/097	0/902	6
S2	0/141	0/85	10
S3	0/099	0/900	7
S4	0/023	0/976	1
S5	0/076	0/923	5
S6	0/087	0/925	4
S7	0/228	0/771	11
S8	0/140	0/859	8
S9	0/145	0/854	9
S10	0/255	0/744	12
S11	0/036	0/963	2
S12	0/058	0/941	3

A sensitivity analysis is presented in Fig 1. It is clear that in some cases like S1 there is no significant differences between the result of MOORA, FMEA and integration of them, but S7 have rank 3 in MOORA, rank 12 in FMEA and final rank is 8.

If we select a supplier based on MCDM and just MOORA method S7 has 3rd rank and choose as a top three suppliers, but after supplier's risk consideration rank of this supplier change significantly in 8.

Table 9 – final result and rank of suppliers

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
FMEA and fuzzy MOORA	0/174	0/157	0/174	0/186	0/202	0/115	0/205	0/122	0/179	0/160	0/148	0/181
Final rank	6	9	7	3	2	12	1	11	5	8	10	4

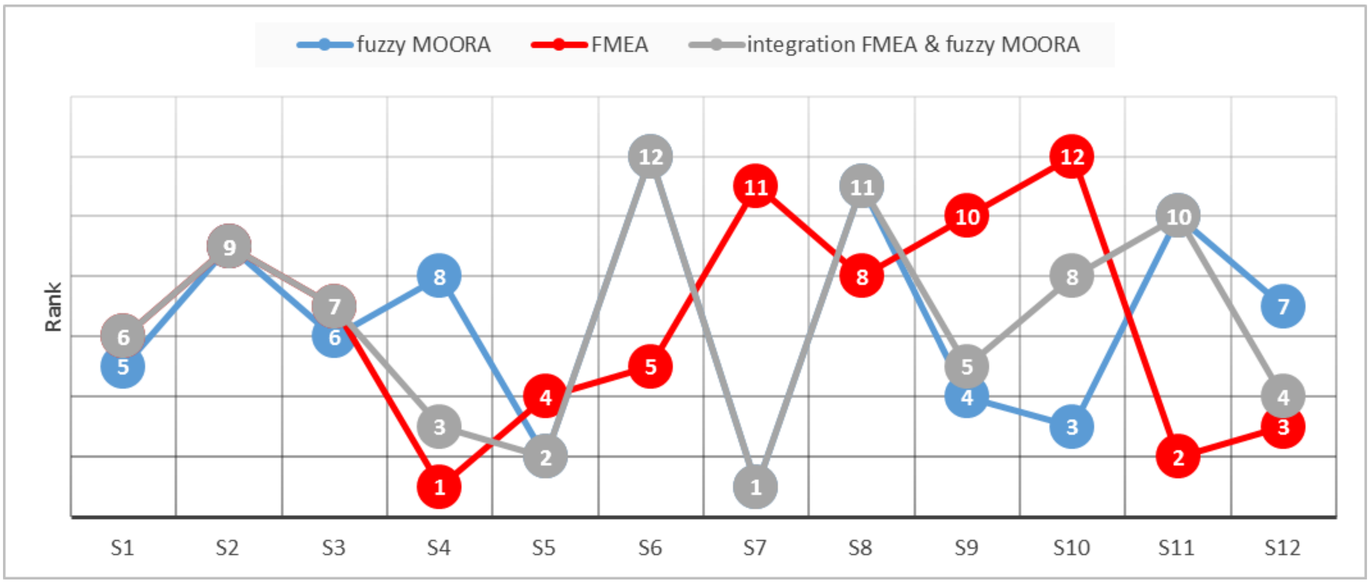

Figure 1 - Performance of the proposed approach in compared to other methods

5. Concluding remarks

Many researches studies used different types of the MCDM methods to evaluate the sustainability of suppliers, but there is a weakness that can be explained as follows:
Suppliers are companies with positive and negative aspects. The basis of MCDM is on the positive dimensions of the supplier, and its efforts to select suppliers with the maximum positive score. However, to have a comprehensive perspective on supplier it is necessary to consider negative aspects of suppliers. Due to the importance of negative considerations, this study uses risk concept as a negative aspect of the suppliers.
To the best of authors' knowledge, suppliers' risks and scores are not assessed together in previous studies. Therefore, the current study is the first research that provides a relation between risk and score by using FMEA technique and fuzzy MOORA method for selecting sustainable suppliers. This novel approach provides a wide perspective on the performance of suppliers.
This study can be extended to different dimensions. First, to deal with the uncertainty of risk and FMEA, gray FMEA can be used. Second, the mathematical programming can be applied to order to allocate the suppliers along with their ranking. Third, the effect of criteria can be evaluated and analyzed by using a regression model before implementation of MCDM.

Appendix: FMEA Evaluation schemes for a real-case application
This Appendix reports the FMEA evaluation schemes for a real-case application of severity, likelihood, and control in Tables 9-11, respectively.

Table 9- Severity scheme

S	cost	quality	delivery	Chemical leakage	Worker safety	Worker dismissal
10	More than 11 % above the market price	More than 6% defeat per batch	More than one week delay	Depletion all shipments	Mass disasters for the workers	More than 25% dismiss
8-9	8 % more than the market price	5% defeat per batch	One week delay	Leakage half a shipment	More than 30% mutilation	20% dismiss
6-7	5 % more than the market price	4% defeat per batch	Half a week delay	30% leakage occurs	More than 20% mutilation	15% dismiss
4-5	4 % more than the market price	3% defeat per batch	One day delay	10% leakage occurs	Partial Mutilation	10% dismiss
2-3	2 % more than the market price	1.5% defeat per batch	Half a day delay	Low leakage occurs	Partial injury	5% dismiss
1	Equal to the market price	1% defeat per batch	on time	Without leakage	Without any incident	without dismiss

Table 10- Occurrence scheme

S	cost	quality	delivery	Chemical leakage	Worker safety	Worker dismissal
10	About 15% happen per period	More than 6 times per period	More than 6 times during time horizon	More than 4 times during time horizon	More than 6 times during time horizon	More than 5 times during time horizon
8-9	More than 10% per period	5 times per period	5 times during time horizon	4 times during time horizon	5 times during time horizon	4 times during time horizon
6-7	About 8% happen during time horizon	4 times per period	3 times during time horizon	3 times during time horizon	3 times during time horizon	3 times during time horizon
4-5	About 6% happen during time horizon	3 times per period	2 times during time horizon	2 times during time horizon	2 times during time horizon	2 times during time horizon
2-3	About 4% happen during time horizon	1.5 times per period	Just 1 times during time horizon	Just 1 times during time horizon	Just 1 times during time horizon	Just 1 times during time horizon
1	Always equal to market price	1 times per period	Always deliver at exactly right time	Always deliver at exactly right time	Never happens	Never happens

Table 11- Detection scheme

S	cost	quality	delivery	Chemical leakage	Worker safety	Worker dismissal
10	No chance to detect	No chance to detect	No chance to detect	No chance to detect	No chance to detect	No chance to detect
8-9	The ability to predict the occurrence a week ago	Random inspection only	Without regular production schedule	Rarely predictable	Rarely predictable	Just a month earlier predictable
6-7	The ability to predict the exact amount fluctuates from a week ago	permissive Sampling inspection	Do not share production schedule	Sometimes predictable	Sometimes predictable	Cannot be determined until the end of the last period
4-5	The ability to predict the occurrence of fluctuations in a prior period	Strict sampling inspection	Non on time access production schedule	Usually predictable	Usually predictable	After two periods of planning is detectable
2-3	The ability to predict the exact amount fluctuates from one period	General inspection before loading	Share production schedule	Most of the time predictable	Most of the time predictable	After one period of planning is detectable
1	Quite predictable before scheduling	Can be detected	From prior period absolutely predictable	Quite predictable	Quite predictable	Before planning quite predictable

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