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Methods of limiting selected risk types in the municipal waste incineration plant

1. Introduction

Risk is a very common phenomenon in the conditions of market economy and every decision made is closely connected with it. Operating in the conditions of risk is an inherent property of each economy. When observing the development of human and their surroundings, one may not ignore the risk which has always existed and been associated with it. Therefore, it may be assumed that broadly understood risk is associated not only with activities but also conditions. Predicting the determined future condition is an indispensable element of each decision but it does not always comply with our expectations. Business operations bear various kinds of risks. Most business entities try to protect themselves from its adverse effects. The development of risk management allows for partial or total risk elimination. In today's quickly developing world, enterprise operations require efficiency and determination. This is the reason why the application of the proper risk management methods for the calculation of potential profits and losses is so important.

The main objective of each enterprise is to increase its value for its owners. High risk may be an effective obstacle to the achievement of this objective. Thus, risk management is a process which forms a very important element of entire enterprise management. The development of risk management methods is associated with the emergence of an increasing number of risk types in business (Bernstein, 1995; Grace et al., 2015; Fotr, et al., 2014). Thanks to skilful activity in the sphere, an enterprise may avoid situations when it fails to reach its goals and it may also restrict losses associated with the appearance of particular hazard types. The operations of an incineration plant entail taking risks in multiple areas but the conditions

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and specific character of work are conducive mainly to the emergence of hazards associated with ecological risk. The purpose of this article is to demonstrate how the most serious dangers affecting such an enterprise as a waste incineration plant can be identified and how losses related to their appearance may be diminished.

2. Risk management methods

Risk identification involves the analysis of opportunities and hazards from the enterprise surroundings with consideration of its strong and weak points. The main instruments used to identify risk are as follows: descriptive risk assessment, inventive (heuristic) methods, e.g. brainstorming, 66 discussion, Delphi method, method of good examples, discovery matrix, Altszuller method, defectuologic method, method of voluntary limitations, etc., analysis of opportunities and risks, early recognition systems, and risk equalisation method (Butler, 2001; Haubenstock and Mude, 2002). The next stage of risk management is risk measurement. Theory of probability is one of the most effective tools for risk assessment. The assessment of risk is a starting point for making decisions on the selection of the appropriate risk manipulation methods. Two types of risk measures may be distinguished: measure at the selection stage and measure at the implementation stage (Bowels, 2004; Tepnan, 2002). Risk may also be measured with the use of probabilistic and statistical methods, sensitivity analysis methods, profile analyses used to compare alternative possibilities, scenario methods, operational methods – used in case of complex risk when other methods are ineffective (Dunett, 2004; Lam, 2003; Schroeck, 2002). The "game strategy" is used most frequently. The third stage is risk control at the strategic level, which involves an analysis of possible solutions and subsequent selection of the most optimum method for risk management. Examples of methods: assuming risk, methods aimed at limiting or eliminating risk causes or insurance against risk consequences (Charsley and Brown, 2002; Nocco and Stulz, 2006). The last stage is risk monitoring and control. Physical and financial risk control methods can be distinguished. Physical control of risk means all activities taken in order to reduce losses. Physical control may involve complete elimination of loss probability or reduction of risk through the use of measures to enable identifying the frequency and extent of damage. Financial risk control involves independent risk management by the company, i.e. retention, or using cash flows to pay potential instalments, sale of assets, special funds, loans, etc. or risk transfer to another entity (Hoyt, and Liebenberg, 2011; Davis and Agliilano, 2002; Chartered Global Management Accountant, 2015). There are no uniform methods of risk management in waste incineration plants as risk has multiple aspects in such enterprises. Aspects may refer to types of hazards – to executives, to employees, to the natural environment, to the probability of occurrence of an adverse event, to the gravity of its consequences, etc. (Bromiley et al., 2014; McShane et al. 2011).

Figure 1 shows a scheme of the main types of risk in a municipal waste incineration plants due to the criterion of their causes. It takes into account the typical types of risks found in specialist literature, as well as new, specific types of waste incineration plants -related threats. The risk management methods presented in this paper will concern ecological risk but they can be used to test each risk type.

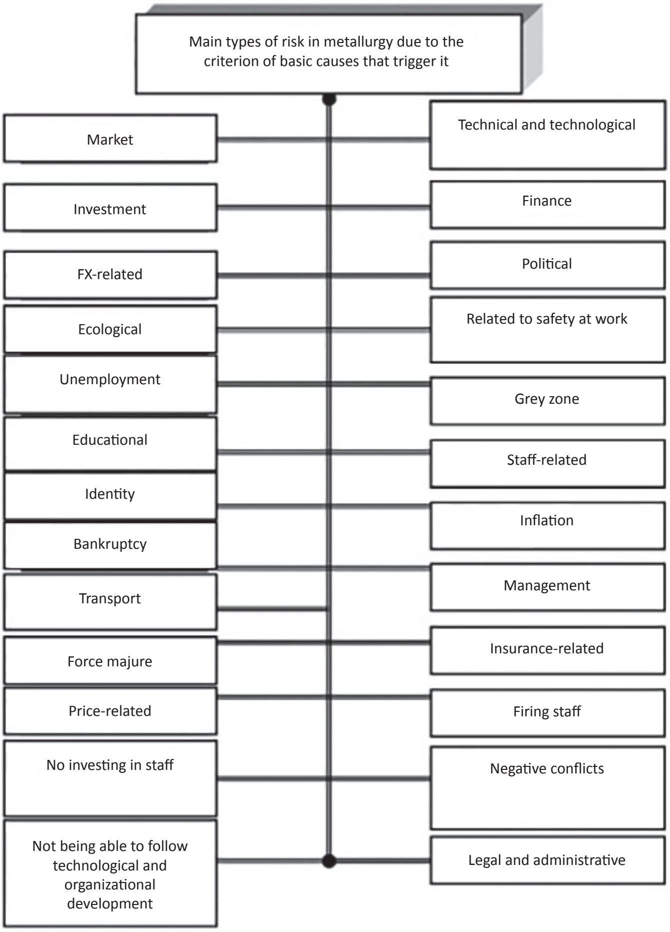

Figure 1. Types of risk in a municipal waste incineration plants due to the criterion of causes – author's study

Source: own study

Ecological risk can be connected with excessive emission of harmful substances and the emergence of large quantities of secondary waste, which accompanies the incineration process. The legislator may increase emission standards concerning the amounts of permissible emission of harmful substances into the air, water and soil, and the management of the incineration plant has not had time to prepare for that. This may mean the imposition of severe penalties for exceeding the standards. Similarly, fees for the storage of production waste may be increased and may result in penalties for breaching requirements in that scope. This may put incineration plants at risk of serious financial consequences.

2. Using the matrix method

The identification of risk areas is the first stage of the described method. The required data includes the most important types of risk and information on how a given company is prepared for the occurrence of this risk, as well as a list of reaction options to the anticipated or emerging risks based on which it will be possible to assess the effectiveness of anti-risk activities in a given company. For this purpose, a chart of analysis of threats and opportunities concerning the analysed risk type should be prepared (Tabs 1, 2). For example, Table 1 shows only eight threats to show the methodology. A three-degree scale was adopted: *l* – low likelihood, *m* – medium likelihood, *h* – high likelihood, *L* – low opportunity/low risk, *M* – medium opportunity/medium risk, *H* – high opportunity/high risk.

Table 1

Analysis of threats connected with ecological risks

Threats	Likelihood	Severity of effects
1. Contamination of air, surface water and ground water, soil	*h*	*H*
2. Emission of secondary contamination to the environment	*h*	*H*
3. Increase of the mass of waste after the incineration process	*m*	*M*
4. Social resistance to locating the incineration plant close to residential areas	*m*	*M*
5. Noise exposure	*m*	*L*

Table 1 cont.

6. Contamination with liquids, threat of slag and furnace ashes	*h*	*H*
7. Low calorific value of waste	*m*	*M*
8. Odour risk	*m*	*L*

Source: own study

Table 2

Analysis of opportunities connected with ecological risks

Possibilities to counteract	**Likelihood**	**Favourability of effects**
1. The use of specific devices and technologies in order to limit the emission of contamination	*h*	*H*
2. The use of a multi-stage system of fume purification, i.e.: dust removal system, acidic gas removal system, dosing of active coke (active carbon) for elimination (adsorption) of polychlorinated dioxins and furans	*h*	*H*
3. Appropriate, rational disposal of waste	*h*	*M*
4. Designing architecturally acceptable and functional incineration plants, which fit well to the surrounding landscape, which in themselves will be sites of architectural	*m*	*H*
5. The location of a municipal waste incineration plant on plots of significant area located in a certain distance from residential areas	*m*	*H*
6. The use of dust emission reduction techniques – electrostatic, condensation and ionising dust collectors, wet scrubbers, fabric filters, cyclones and multi-cyclones	*h*	*H*
7. Mixing municipal waste with a more calorific fuel, e.g. coal or high-calorific industrial waste	*h*	*M*
8. The use of vacuum deodorising installations	*h*	*H*

Source: own study

The conducted analysis of threats and opportunities has allowed the author to distinguish the most significant factors affecting the ecological risk in a negative or positive way.

The most significant risks which should be dealt with first are risks number: 1, 2, 6. In turn, the major possibilities to counteract the negative effects of threats connected with ecological risks are: 1, 2, 6, 8.

The next step involves risk assessment, i.e. numerical expression of the extent of threats or opportunities associated with a given risk to make an assessment. To this end, a matrix is used to strengthen the reaction between the probability of occurrence and severity or favourableness of effects in relation to the number of indications for particular relationships, using the data from tables 1 and 2. Counted, identical relations have been entered into the relevant fields of the matrix (Tabs 3, 4). Then, groups of factors were distinguished: A, B, C. GR. A are events that occur between: *hH*, *hM*, *mH*. GR. B are events that occur between: *lH*, *mM*, *hLl*. In turn, GR. C are events that occur between: *lM*, *lL*, *mL*. Then, a quantitative and qualitative comparison was made in each group to compare chances and risks.

Table 3

Matrix of relations: opportunities – probability – severity/favourableness concerning ecological risk

		Severity			**Favourableness**		
		H	***M***	***L***	***H***	***M***	***L***
Probability	*h*	3	0	0	4	2	0
	m	0	3	2	2	0	0
	l	0	0	0	0	0	0

Source: own

The quantitative analysis (Tab. 4) involves summing up individual events taking place in groups. For severity: $S_{DA} = hH + hM + mH = 3 + 0 + 0 = 3$, $S_{DB} = lH + mM + hL = 0 + 3 + 0 = 3$, $S_{DC} = lM + lL + mL = 0 + 0 + 2 = 2$, $S_Z = S_{DA} + S_{DB} + S_{DC} = 3 + 0 + 2 = 5$. For favourableness: $S_{KA} = hH + hM + mH = 4 + 2 + 2 = 8$, $S_{KB} = lH + mM + hL = 0 + 0 + 0 = 0$, $S_{KC} = lM + lL + mL = 0 + 0 + 0 = 0$, $S_S = S_{KA} + S_{KB} + S_{KC} = 8 + 0 + 0 = 8$.

Table 4

Quantitative analysis of severity/favourableness indicators concerning ecological risk

	For severity	For favourableness
Gr. A	$K=\frac{S_{DA}}{S_Z}=\frac{8}{17}=0.47$	$K=\frac{S_{KA}}{S_S}=\frac{14}{17}=0.82$
Gr. B	$K=\frac{S_{DB}}{S_Z}=\frac{5}{18}=0.29$	$K=\frac{S_{KB}}{S_S}=\frac{3}{17}=0.17$
Gr. C	$K=\frac{S_{DC}}{S_Z}=\frac{4}{17}=0.23$	$K=\frac{S_{KB}}{S_S}=0$

Source: own

Cumulative tally of quantitative and value-wise assessment of opportunities and risks is presented in Table 5.

Table 5

Cumulative tally of quantitative and value-wise assessment of opportunities and risks

	Severity		Favourability	
	quantity	value	quantity	value
Gr. A	3	0.6	8	1
Gr. B	3	0.6	0	0
Gr. C	0	0.4	0	0

Source: own

As shown in Table 5, for favourability, factor group A having the most significance for the proper functioning of an incineration plant connected with threats concerning ecological risks assumes the value of 0,6; while for severity, where group A causes most adverse effects connected with such risks, it assumes the value of 1. This means that actions aimed at reducing the listed threats need to be undertaken, as they are economical (Kubińska-Jabcoń, 2018).

4. Using the modified FMEA method

FMEA method – the analysis of causes and effects, a method that companies use to prevent and mitigate the effects of defects. Its purpose is to identify and assess the risk associated with weak points that occur during production planning and the manufacturing process, which significantly reduces this risk (Shahin, 2004; Vacik, Fotr, Špaček and Souček, 2014). The risk priority number – RPN – is a product of integral numbers rom the range (1–10) that describe the frequency of a defect (risk of defect: 1 – low probability, 10 – high probability). Number (*R*), meaning of defect for the client: 1 – negligible importance, 10 – significant. Number (*Z*), detection level; describes the probability that a defect will not be detected by the manufacturer and will go to the client: 1 – easy to detect, 10 – hard to detect. Number (*W*), the values that RPN can take are in the range from 1 up to 1000. The higher the RPN value, the greater the risk associated with a defect. The assessment indicator in the FMEA method – the number of priority risk is:

$$RPN = P \cdot Z \cdot T \tag{1}$$

where:

- P – probability of error/defect,
- Z – meaning for the client,
- T – ease of detection.

Modified FMEA method has been used to assess risk in the municipal waste incineration plant. Indicators are adopted based on Table 6 (Kubińska-Kaleta, 2008).

Table 6

Adopted scale for P, H_s, T indicators

$P_R P_M$		H_s		T_R/T_M	
Low chance of occurrence	1	No significance	1	Very easy to counteract / very difficult to apply	1
Very unlikely	2–3	Low significance	2–3	Easy to counteract / difficult to apply	2–3

Table 6 cont.

Unlikely	4–6	Average significance	4–6	Medium difficult to counteract / can be applied	4–6
Rather likely	7–8	High significance	7–8	Very difficult to counteract / easy to Apple	7–8
Very likely	9–10	Very high significance	9–10	Cannot be counteracted / very easy to apply	9–10

Source: own

For the purposes of the study of risks occurring in industrial plants, a modification has been proposed consisting in adjusting the RPN indicator, and following designations have been assumed:

$$C_R = P_R \cdot H_S \cdot T_R \quad (2)$$

$$C_M = P_M \cdot H_S \cdot T_M \quad (3)$$

where:

C_R – risk assessment indicator,
C_M – opportunity assessment indicator,
P_R – likelihood of occurrence of a given risk,
P_M – likelihood of occurrence of a given opportunity,
H_S – significance for the proper functioning of an incineration plant,
T_R – difficulties in counteracting a risk,
T_M – ease of adjusting given opportunities.

Numbers C_R and C_M are integral numbers from the range (1.1000). If the number is significantly greater than one, preventive measures should be taken (in case of risk); or a given threat can be easily counteracted (if possible). To be able to effectively counteract the risks and to make these activities profitable, $\Sigma C_M < \Sigma C_R$. In accordance with the scale adopted above, particular types of threats related to a given risk were considered. After calculations: sum of C_R indicator: 6221, sum of C_M indicator: 9873. $\sum C_M < \sum C_R$, so the risk can be effectively counteracted and those actions are economical.

5. The application of FTA method with reference to the analysed risk

Fault tree analysis (FTA) is an ordered graphic representation of specific conditions and other factors which cause or contribute to the occurrence of a specific adverse event, also known as the “top event.” The representation is made in such a form as to be comprehensible and enable the analysis and change of a tree to facilitate the determination of:

– factors affecting reliability and characteristics which describe system functioning, e.g. type of element unfitness, operator’s error, conditions of surroundings, programming errors;
– contradictory requirements which may affect faultless functioning;
– combined events affecting more than one functional element of the system which may destroy the benefits resulting from the use of the redundancy of reliability structures.

The analysis of systems using redundancy trees is a deductive (top-down) method aimed at identifying causes or combinations of causes which may lead to a specific top event. The analysis may be a quality analysis or, in specific cases, also a quantitative analysis. The process of tree creation begins with the identification of a top event. The event is an output of a top logic gate while the relevant input events identify possible causes and conditions of the occurrence of a top event. Each input event may also be an output event of a lower-level logic gate. If an output event of the gate determines the incapacity to perform the assumed function, the corresponding input event may describe the incapacity of the device or its functional limitations. If an output event means damage to the device, the relevant input event may be the defect of a device, lack of control and basic power supply provided that these events may actually happen and they have not been incorporated earlier as parts of limitations in device functioning.

The extension of a tree branch ends when one or more of the following events take place:

– basic events, i.e. independent events for which important characteristics may be defined differently than with the use of a fault tree;
– events which need not be extended;
– events which were or will be further extended in another fault tree (PN-EN 61025:2007 Fault Tree Analysis).

Figure 2 shows a fragment of a fault tree for the analysed types of risk.

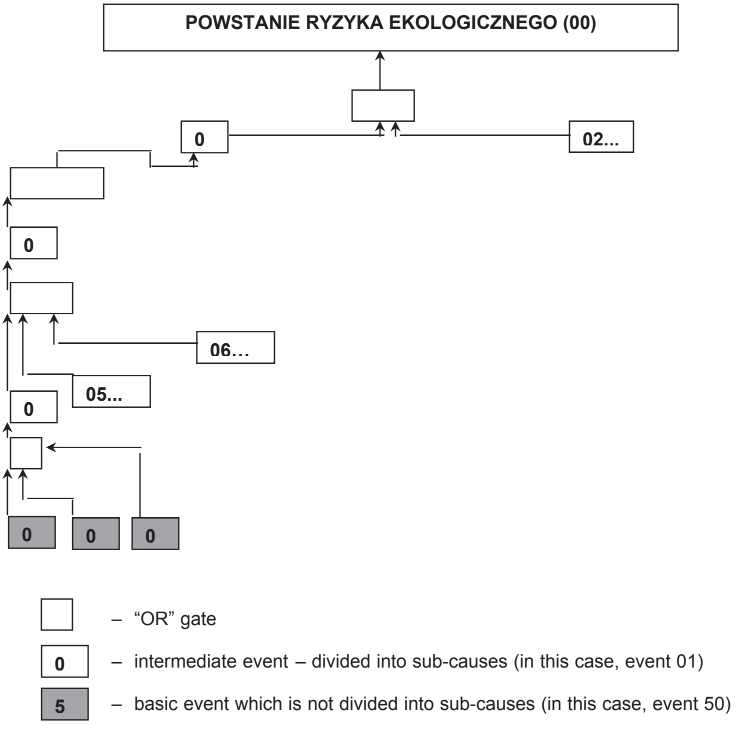

Figure 2. Fault tree

Source: own

Explanation:

01 – air pollution, contamination of surface and underground waters, soil and fossil deposits, people, fauna and flora, landscape, material goods,

02 – increasing the mass of waste after the combustion process... (this tree branch should be extended similar to the presented example starting with hazard 01),

03 – emission of secondary contamination to the environment as matter is not destroyed in combustion but only changes its form and chemical composition,

04 – contamination which goes to water,

05 – pollution with dusts,

06 – danger of slags and combustion ashes,

07 – wastewater from devices controlling air pollution, e.g. salts, heavy metals,

08 – final process of discharging wastewater from the treatment plant, e.g. salts, heavy metals,

09 – water from the boiler room – leaks during boiler blow-out, e.g. salts.

When using the FTA fault tree and the proposed solutions, an algorithm must be created in the next step to separate basic events corresponding to ecological risk. The first step after algorithm starting is to check if ecological risk has not increased. If not, the algorithm stops; if yes, the algorithm looks for causes in the subsequent steps. The second step is to start a loop which is the main part of the algorithm. It involves the verification of all factors which increase ecological risk and have earlier been included in the designed fault tree. Beginning with the first conditional instruction inside the loop, note that the algorithm uses the effects produced by the fault tree, which makes them closely connected. The conditional instruction retrieves data from the fault tree on whether i-th event is basic, and then, based on the instruction, it goes further, depending on the value obtained from FTA, i.e. if the condition is fulfilled, it goes to the next conditional instruction; if not, the next event is verified. If it is assumed that the condition is met, or the currently tested event is a basic event, the next conditional instruction checks if the tested basic event occurs. If not, then the next event is checked and if so, when possible, the algorithm suggests the solution to be used to eliminate or limit an adverse event or prompts preventive activities to be taken so that the event would not be a problem again in the future. Here, the algorithm is a tool to efficiently locate adverse events increasing ecological risk and to quickly obtain information on how to counteract them (if possible).

In that case, the treatment algorithm would not work without a fault tree thanks to which basic events on which its procedures are based may be separated (Kubińska-Kaleta, 2008).

Preventive activities:

07' – appropriate management of process waste from exhaust fumes treatment,
08' – appropriate management of process waste from exhaust fumes treatment,
09' – appropriate management of process waste from exhaust fumes treatment.

The examples of the application of this solution may be seen in Vienna where cake wash strainers from the wet purification of exhaust fumes are taken to waste disposal sites in salt workings, outside the territory of Austria.

6. Conclusions

In order to manage risk effectively, an enterprise should determine areas of risk, its extent, ways of influencing activity, process, organisation, and steps to take in order to eliminate or restrict risk to an acceptable level. Risk management may bring expected effects, e.g. reduce losses when activities are undertaken in the enterprise in a continuous and effective manner. As the results of the research carried out using two methods show, threats associated with risk play a huge role in a company's proper functioning.

In method I, a group of factors with the most significance for the proper functioning of an enterprise for favourable phenomena exceeded the group of factors causing the most adverse effects connected with a given risk, which indicates that actions limiting or eliminating such risk are economical.

In method II, the sum of C_R indicator is smaller than the sum of C_M indicator, which means that it is economical to take actions aimed at limiting or eliminating such risks.

At the final stage, based on the obtained results, it is possible to create an algorithm that would monitor the analysed risk, which would aim to isolate the basic event responsible for the creation of ecological risk, using the FTA fault tree and the proposed solutions.

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