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The costs of industrial accidents for the organization: Developing methods and tools for evaluation and cost–benefit analysis of investment in safety

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ABSTRACT

This paper proposes methods for reliable evaluation of the costs involved in industrial accidents for an organization – especially in relation to loss of production. We use a management approach that is based on the "Theory of Constraints". Industrial accident costs contain two major cost-categories: direct costs and indirect ones. While direct costs are easily recognizable indirect costs cannot always be easily recognized attributed to the accident. The research shows the importance of evaluating indirect costs and develops a model that calculates the real cost of an accident.

1. Introduction

This paper proposes methods for reliable evaluation of the costs involved in industrial accidents for an organization – especially in relation to loss of production. We use a management approach that is based on the "Theory of Constraints" (TOC) developed in the 1980s. TOC was planned to overcome a management failure resulting from the approach of "management by numbers" which put the American industry in an inferior position as compared to Japan. The core of the TOC is that the entire functioning of a production system is constrained by its "bottlenecks" so these points in the production process have to be managed carefully in order to reach full production capacity (Nahmias, 2001). We take this approach to develop reliable measurement methods of accident costs.

The damage caused by industrial accidents is mainly a function of the accident location in the production chain. The distinction between types of damage as a function of location is therefore critical and not at all trivial. On one hand, the number of work stations which are bottlenecks is usually small while, on the other hand these stations are the most loaded which may result in safety failures and thus accidents. Our goal is to develop a model that takes these aspects into account.

Many studies have concluded that the true cost of industrial accidents for an organization is significantly higher than the direct costs (Corcoran, 2002; Dorman, 2000; Heinrich, 1959; LaBelle, 2000; Michaud, 1995; Monnery, 1998; Neville, 1998; Shim & Siegel, 2000). The real challenge is to develop a reliable evaluation of indirect costs which are usually also the uninsured costs. Direct costs such as compensation, medical care and new equipment are usually easy for pricing and are usually insured, so the tendency is usually to concentrate on them (LaBelle, 2000; Neville, 1998; Vincoli, 1994).

The reliable evaluation of the cost of industrial accidents for an organization can help managers and workers to internalize the importance of safety measures from an economic-managerial perspective, and to locate the work stations that require investment in safety measures. Also, reliable evaluation assists managers to correctly plan investment in safety measures. Indeed, Dastous, Nikiema, Maréchal, Racine, and Lacoursie're (2008) argue that in order to manage risk properly, it will be necessary to define, implement and improve a series of processes and most importantly, provide guidance to managers (Kletz, 2001; Richardsson, & Impgaard, 2002).

The paper proceeds as follows. In the next section, we present a theoretical background for the model. In the third section, we present the model and numerical example of the calculations. The fourth section concludes the paper.

2. Theoretical background

Most organizations do not systematically calculate accident costs, owing to managers' lack of knowledge and understanding of

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the compensation mechanisms involved in accidents. Managers tend to believe that most expenses are insured and therefore do not see a real reason to calculate these costs which requires data collection. Furthermore, the common economic approach for calculating the advantages of safety investment is based on the assumption that managements regard industrial accidents as undesired side effects, while their direct and indirect costs are assumed to be a kind of sank costs (Oi, 1974; Thaler & Rosen, 1975). According to this approach, the optimal organizational investment in safety is calculated by a standard model of profit maximization. The implicit assumption is that accidents may be productive for the organization and prevention is advantageous only if it can produce marketing and reputation benefits. Adnett and Dawson (1998) criticize this approach, arguing that the calculation method should include organizational, social and macro-economic parameters. One of the goals of the current paper is to provide tools which will help overcoming the narrow economic approach adopted by many managers.

Other possible reasons for the marginalization of accident costs by managers include: measurement difficulties, overloaded managers, biased accounting methods and the low status of safety departments (Dorman, 2000). Dastous et al. (2008) suggest that to manage risk properly, not only necessitates the development techniques but also to develop processes, at the personnel level as well as at the organizational level, which will take human nature into account. Appropriate mechanisms will also have to be set up to reconcile "public interest" and "risk management". It will thus be necessary to define, implement and improve a series of processes and most importantly, provide guidance to managers.

The real challenge in evaluating the costs of industrial accidents is to develop reliable evaluation of indirect costs which are usually also the uninsured costs. Yet, researchers have recognized also the importance on indirect costs. For example, LaBelle (2000) suggests a method for cost evaluation based on several categories: cost of time spent in relation to medical care, reduced production of the injured worker after returning to work, cost of supervision and investigation, reduced production, cost of replacement, learning and management cost and cost related to legal processes. Yet, the methods used for these evaluations are relatively old and especially lack integration of central components in the production process. Therefore, they may be regarded not reliable by managers.

The model we propose assume that as the workload increases, whether it is mental or physical workload, the probability of industrial accidents increases. This assumption is supported in the literature both theoretically and empirically (Adnett & Dawson, 1998; Sanders & McCormick, 1992: 667; Sanders & Shaw, 1988). Since the definition of a bottleneck station refers to the workload which characterizes this station, we infer that the probability for industrial accidents is relatively higher in bottleneck stations as compared to other locations in the production process.

3. The model

In order to construct a model for estimating the total cost of an industrial accident, we take into account all parameters that reflect the possible costs imposed by the accident. We start by presenting the general structure of the model in which the total cost of an industrial accident is the sum of its direct costs (C_{direct}), indirect costs (C_{indirect}), payment (C_{payment}) and immeasurable costs ($C_{\text{immeasurable}}$).

$$\text{Total cost} = C_{\text{direct}} + C_{\text{indirect}} + C_{\text{payment}} + C_{\text{immeasurable}} \tag{1}$$

The parameters that reflect the direct costs are formulated as

$$C_{\text{direct}} = C_{\text{damage}} + C_{\text{medical}} + C_{\text{fine}} + C_{\text{insurance}} \tag{2}$$

where

C_{damage}- The damage of products, equipment and machinery. Very often, an accident not only entails injuries, but also includes damage of products, equipment and machinery. This cost includes, among other things, the damage caused to machinery, raw-materials, damaged equipment, and the cost of cleaning and returning the working area back to functioning.

C_{medical}- Immediate medical treatment costs. This cost includes payment to evacuation to the hospital, payment for treatment given at the site of the accident, hospitalization, and the medical equipment that becomes unusable after the accident.

C_{fine}- If an accident is caused due to violations of safety procedures or even breaking the law, the organization may be exposed to fines and claims given by the authorities.

$C_{\text{insurance}}$- The premium increase. The annual payment a company pays as an insurance premium is determined according to an estimate of absence leave, number of hospitalization days, the severity of the accident, potential lawsuits and the financial damage of equipment, commodities and facilities. The premium varies from year to year according to the events occurring in the previous year. Thus, an accident can cause an increase of the insurance premium of the following year. Since the premium increase is a direct cause of an accident, the difference between the previous payment and the new payment can be regarded as a direct cost. In addition, $C_{\text{insurance}}$ also includes all legal expenses due to different lawsuits charged by either the authorities or the employees.

The parameters which reflect the indirect costs are formulated as (Appendix 1 presents the specific calculations for each parameter):

$$C_{\text{indirect}} = C_{\text{capacity lost}} + C_{\text{schedule}} + C_{\text{recruit}} + C_{\text{work time}} + C_{\text{wip}} + C_{\text{mang}} \tag{3}$$

where

$C_{\text{capacity lost}}$- The costs resulting from capacity loss. An accident can cause a slowdown in production and even halt it for a period of time, for example, evacuation of the injured workers and damage to the equipment which should be handled immediately (like fire). Also, an accident may result in a new bottleneck causing production processes to slow down and imposed additional costs.

C_{schedule}- When an accident occurs, slowdown in production will affect the time table schedule and causing damages to the client. Clients can cancel the contract or demand a lower price. There may be solution that the company will create the absented product by contractor that will help the company to handle the schedule.

C_{recruit}- The cost of hiring additional workers to replace the injured ones, which includes the time invested in recruiting and training the new workers.

$C_{\text{work time}}$- The work managers invest in investigating the accident. Work time is also dedicated to instruction of the simple workers. Also the additional work hours that needed to replace the injured worker (it depends on the policy of the company if there are recruiting new workers or letting the senior to work extra hours).

C_{wip}- When an accident occurs, it creates a new bottleneck. As a result, the inventory starts to grow and accordingly the cost connected to it grows as well. Managers need to find a solution to fit the inventory to the new bottleneck which will cause additional expenses. This cost is handled by specific managers and hence may vary from company to company based on managerial considerations.

C_{mang}- The cost connected to the CEO time. The CEO time is very expensive and wrong usage of time can cause the company to lose sales. We suggest that the time invested by the CEO can be translated into the sales of the company (see Appendix 1).

The parameters which reflect payment ($C_{payment}$) are formulated as:

$$C_{payment} = M(\mathrm{Pay}_{new} W_1) + \sum_{i=1}^{W_2} B_i - \mathrm{NI} \times W_2 \qquad (4)$$

The above expression describes the added marginal cost due to the accident, and therefore, only the relative change of cost should be taken into consideration. Since there is a refund from the Social Security Institute, its value is subtracted from the cost function.

Pay_{new}- The payroll of a new employee.

M- Number of months the injured worker is replaced.

W_2- Number of injured workers.

B_i- Benefits (in money terms) given to the injured worker. Every worker is entitled to different benefits in accordance with his seniority. In the case of an accident, the organization must continue to pay these benefits.

NI- National insurance refund.

The parameters composing the immeasurable costs are:

$$C_{immeasurable} = C_{reputation} + C_{morale} \qquad (5)$$

where

$C_{reputation}$- Damage done to the company's reputation might result in customers turn to competitive suppliers (the numerical estimation of the reputation damage is beyond the scope of this paper).

C_{moral}- Impact on the morale of the workers. An accident may hurt the workers' morale and motivation, causing absence from work, tardiness and a higher rate of worker substitution. Moreover, workers might demand salary-increases for endangerment in the working place. Since this is a psychological and an emotional cost, the numerical estimation of this damage is currently not measurable.

4. Empirical examples

In this section we perform a cost calculation of an accident (an additional calculation is given in Appendix 2). We model the accident cost using historical data taken from an Israeli industrial company. To preserve firm's privacy we used a linear transformation of data.

The accident presented in the following table occurred in a chemical facility, where an explosion caused the injury of two workers. Each one of the injured workers was evacuated by ambulance. Thus, the total of two ambulances was needed for evacuation. The injured workers were hospitalized and, in total, missed 6 working days.

For every facility, in this specific company, there is a backup. Therefore, production was not hurt due to the accident, and no new bottleneck was created.

The damage to the products summed up to 50,000$ (C_{damage}), and the fine due to damage to the environment was 2000$. In addition, a policyholder's participation of 50,000$ was paid for covering the damage of the facility.

4.1. Direct cost

$$C_{direct\ cost} = C_{damage} + C_{medical} + C_{fine} + C_{insurance}$$
$$C_{direct\ cost} = 50,000 + 2600 + 2000 + 50,000 = \$104,600$$

	Value ($)	Remarks
C_{damage}	50,000	The damage to the facility and products
$C_{medical}$	2600	175$ ambulance ×10 times + 375$day in hospital × 6
C_{fine}	2000	Fine due to damage to the environment
$C_{insurance}$	50,000	Policyholder's participation

4.2. Indirect cost

$$C_{indirect} = C_{capacity\ lost} + C_{schedule} + C_{recruit} + C_{work\ time} + C_{wip} + C_{mang}$$

Parameter	Value ($)	Remarks
$C_{capacity\ lost}$	0	For every facility, in this specific company, there is a backup. Therefore, production rate was not hurt due to the accident
$C_{schedule}$	0	In spite of the severe accident, all products were supplied to customers
$C_{recruit}$	1500	10 workers × training cost $750 and no recruit cost
$C_{work\ time}$	21,850	In the cost of work hour we relate to a global payment per hour disregarding the rank (except CEO), which is 50$. Two hundreds workers were junior managers who spent 5 h on instruction after the accident. Ten workers worked 4 extra hours 3 weeks 5 days in a week which the first 2 h was 125% salary and the second 2 h where 150% salary. Three managers spent 3 weeks 5 days in week and 8 h a day investigating the accident. The cost is calculated as: 50 × 5 × 200 + 3 × 5 × 8 × 50 + 10 × 3 × 5 × 2 × 62.5 + 10 × 3 × 5 × 2 × 75
C_{wip}	0	
C_{mang}	228,000	The CEO wasted only 30 min. CEO works 250 h per month, the percentage of time spent on accident is: $Z = (0.5 \times 100)/(250 \times 12) = 0.0167\%$ The company is with outside supervision so potential loss in sales increase is (see Appendix 1 for details): $W = 0.0167/0.11 = 0.152\%$ Clear profit from sales from the last year is $150,000,000 So the company's loss from the CEO loss of time on accident is: (150,000,000 × 0.152)/100

$$C_{indirect} = 228,000 + 21,850 + 1500 = \$251,350$$

The total cost is $355,950.

We can see that the indirect costs are 2.415 times larger than the direct ones, yet most companies do not regularly calculate these costs. We can conclude that this particular company lost much more money than had been expected.

Additional example is presented in Appendix 2.

5. Conclusion

This paper demonstrated the importance of evaluating indirect costs and suggests a model which calculates the real cost of an accident. The damage caused by industrial accidents is mainly a function of the accident location in the production chain. The distinction between types of damage as a function of location is therefore critical and not trivial at all. On one hand, the number of work stations which are bottlenecks is usually small while on the other hand these stations are the most loaded which may result in safety failures and thus accidents. In this paper, we developed a model that considers all these aspects.

A reliable evaluation of the cost of industrial accidents for the organization is important for several reasons. First, such evaluation can lead managers and workers to internalize the importance of safety measures from an economic-managerial perspective. Second, a reliable evaluation can help locating the work stations that require much consideration and investment in safety measures. Third, a reliable evaluation which also provides risk evaluation can help managers to plan correctly the investment in safety measures.

Appendix 1

The expression for the indirect cost is:

$$C_{\text{indirect}} = C_{\text{capacity lost}} + C_{\text{schedule}} + C_{\text{recruit}} + C_{\text{work time}} + C_{\text{wip}} + C_{\text{mang}}$$

We now show in detail, how to compute each component of the indirect cost.

$$C_{\text{capacity lost}} = \int_0^{t_1} \text{ufh}_{\text{old}} \text{Pr} dt + \max\left(\int_{t_1}^{t_2} (\text{ufh}_{\text{old}} - \text{ufh}_{\text{new}}) \text{Pr} dt, 0\right) + \text{Re Cre}$$

t_1- The short-term period right after the accident – the time duration when the production line stops working, starting from the time of the accident.

t_2- The long-term period right after the accident – the time duration from the time the production line is reactivated after the accident to the time when the production line goes back to the previous manufacturing rate.

Pr- Profit per unit.

ufh_{old}-Production rate of the bottleneck station before the accident.

ufh_{new}- Production rate of the bottleneck station after the accident. If there is damage in a certain area, the production rate there might be smaller than the initial rate. Therefore, a new bottleneck station is likely to appear.

Re- Number of units that have been damaged in the accident but can be fixed.

Cre- Working cost these unites.

$$C_{\text{schedule}} = F_o \text{Nco} + F_a \text{Nca} + K \sum_{i=1}^{\text{Nol}} d_i + Q(P - M)$$

F_o- Fines for a canceled order – if the company cannot deliver orders due to the accident (since it needs to shut down production), it may have to pay a fine.

F_a- Fines for a canceled contract – if the company cannot supply for existing customers due to the accident (since it needs to shut down production).

Nco- Number of canceled orders.

Nca- Number of canceled contracts.

K- Fines due to delays in deliveries.

Nol- Number of orders that were delivered late.

d_i- Number of days of tardiness for order i.

Q- Number of units given by outsource contractor (in order to preserve ongoing orders).

P- Cost per unit supplied by outsource supplier.

M_a- Material cost per unit.

$$C_{\text{recruit}} = W_1(r + l)$$

r- Hiring cost (include advertising, interview, manpower agencies etc.)

l- Training cost for a new employee.

W_1- Number of new recruited worker.

$$C_{\text{work time}} = \sum_{i=1}^{n} T_i C_i + \sum_{i=1}^{l} \sum_{j=1}^{k} P_i H_{i,j}$$

T_i- Number of hours devoted by worker i to investigations, lawsuits, visiting the injured, etc.

C_i- Cost (per hour) of the wasted time.

P_i- Cost for overtime hours for worker i.

H_{ij}- Number of overtime hours for worker i in time period j (for example, for the first 2 h the worker gets 125% of his hourly salary, and for the next 2 h 150%). Thus, the first 2 h are the first time period and the late 2 h are the second time period.

C_{wip}- When an accident occurs, it creates a new bottleneck. As a result, the inventory starts to grow and accordingly the cost connected to it grows as well. Managers need to find a solution to adjust the inventory to the new bottleneck which will cause additional expenses. This cost is to be handled by specific managers and hence may vary from company to company based on managerial aspects.

$$C_{\text{mang}} = \begin{cases} \dfrac{T_p}{P_1} \times T \times C & \text{if management-controlled firm} \\ \dfrac{T_p}{P_2} \times T \times C & \text{if externally-controlled firm} \end{cases}$$

The above expression describes the connection between CEO time wasted on accidents and potential sales losses. The relationship between the increasing sales and CEO salary is also taken into account. We assume that the time the CEO spends on dealing with the accident hurts the company's future sales, and consequently the CEO own salary.

T_p- Percentage of time devoted to dealing with the accident by the CEO.

T- Percentage net profit from last year's sales.

C- Net profit from last year's sales.

P_1- The percent increase in the CEO's payroll, for every percent increase of corporate. If the company is controlled by at least one shareholder who owns more than 5%, the company is regarded as a *management-control* (Hambrick & Finkelstein, 1995). According to Hambrick and Finkelstein (1995), the value of P_1 is 0.37, i.e. for every percent of increase in sales, the CEO's salary grows by 0.37%.

	Value ($)	Remarks
C_{damage}	10,000	Since the accident occurred in a nonterminating production line, stopping it caused damages in products in that line
C_{medical}	8050	175$ ambulance ×1 time + 375$day in hospital × 21
C_{fine}	0	
$C_{\text{insurance}}$	0	

P_2- The percent increase in the CEO's payroll, for every percent increase of corporate sales in an externally controlled firm.

A company is *externally controlled* if none of shareholders holds more than 5% (Hambrick & Finkelstein, 1995). According to Hambrick and Finkelstein (1995), the value of P_2 is 0.11, i.e., for every percent of increase in sales, the CEO's salary grows by 0.11%.

Appendix 2

The accident presented in the following table occurred in a chemical facility, where an employee was accidentally connected to a nitrogen mask instead of an oxygen mask. The facility stopped working for an hour; the worker was evacuated to intensive care and was hospitalized for 3 weeks. In those 3 weeks, an outsourcing worker was recruited. For the first 3 days, while he was recruited and being taught, for 30 working hours, co-workers replaced the injured worker and were paid for extra hours at the rate of 125%. In order to investigate the accident, three team managers dedicated 1 working day and after that gathered all the workers (30 workers) for 45 min (during office hours) for guidance and instructions.

The accident was not reported to the insurance company, and the CEO time spent for the accident is negligible.

Parameter	Value ($)	Remarks
$C_{capacity\ lost}$	0	For every facility, in this specific company, there is a backup. Therefore, production rate was not hurt due to the accident
$C_{schedule}$	0	All products were supplied to customers
$C_{recruit}$	750	1 worker $\times$ training cost $750 and no recruit cost
$C_{work\ time}$	13,850	In the cost of work hour we relate to a global payment per hour disregarding the rank (except CEO), which is 50$. For 3 days 15 workers worked 2 extra hours each, for a rate of 125% per hour. In addition the outsourcing worker was paid for 15 working days, 9 h each day. $50 \times 1.25 \times 30 + 90 \times 50 \times 15 = 9875\$$ In addition, the facility stopped working for an hour, while 30 workers were paid – $30 \times 50\$ = 1500\$$, an investigation for the accident took 1 day and consisted of three team managers: $3 \times 9 \times 50\$ = 1350\$$, and special guidance, for 45 min, to all the 30 workers – $0.75 \times 30 \times 50 = 1125\$$
C_{wip}	0	There is no new bottleneck station
C_{mang}	0	The CEO wasted no time on accident

Direct cost

$$C_{direct\ cost} = C_{damage} + C_{medical} + C_{fine} + C_{insurance}$$

$$C_{direct\ cost} = 10,000 + 8050 = \$18,050.$$

Indirect cost

$$C_{indirect} = C_{capacity\ lost} + C_{schedule} + C_{recruit} + C_{work\ time} + C_{wip} + C_{mang}$$

$$C_{indirect} = 13,850 + 750 = \$14,600.$$

The total cost is $32,650.

Even in small accident the indirect cost weights 44.71%.

References

Adnett, N., & Dawson, A. (1998). The economic analysis of industrial accidents: a re-assessment. *International Review of Applied Economics, 12*, 241–255.
Corcoran, D. (2002). The value of estimating the hidden costs of accidents. *Occupational Health and Safety, 71*, 26–30.
Dorman, P. (2000). *Three preliminary papers on the economics of occupational safety and health*. Geneva: International Labor Organization.
Dastous, P. A., Nikiema, J., Maréchal, D., Racine, L., & Lacoursie're, J. P. (2008). Risk management: all stakeholders must do their part. *Journal of Loss Prevention in the Process Industries, 21*, 367–373.
Hambrick, D. C., & Finkelstein, S. (1995). The effects of ownership structure on conditions at the top: the case of CEO pay raises. *Strategic Management Journal, 16*(3), 175–193.
Heinrich, H. W. (1959). *Industrial accident prevention*. New York: McGraw Hill.
Kletz, T. A. (2001). *Learning from accidents*. Oxford: Gulf Professional.
LaBelle, J. E. (2000). What do accidents truly cost? *Professional Safety, 45*, 38–42.
Michaud, P. A. (1995). *Accident prevention and OSHA compliance*. New York: Lewis Publishers.
Monnery, N. (1998). The cost of accident and work related ill-health to a cheque clearing department of a financial services organization. *Safety Science, 31*, 59–69.
Nahmias, S. (2001). *Production and operations analysis*. Boston: McGraw-Hill.
Neville, H. (1998). Workplace accidents: they cost more than you might think. *Industrial Management, 40*, 7–9.
Oi, W. (1974). On the economics of industrial safety. *Law and Contemporary Problems, 38*, 669–699.
Richardsson, P. M., & Impgaard, M. (2002). Corporate cost of occupational accident: an activity based analysis. *Accident Analysis and Prevention*173–182, Pergamon.
Sanders, M. S., & McCormick, E. J. (1992). *Human factors in engineering and design*. New York: McGraw-Hill.
Sanders, M. S., & Shaw, B. (1988). *Research to determine the contribution of system factors in the occurrence of underground injury accidents*. Pittsburgh, PA: Bureau of Mines.
Shim, J. K., & Siegel, J. G. (2000). *Modern cost management and analysis*. New York: Barron's Business Library.
Thaler, R., & Rosen, S. (1975). The value of saving a life: evidence from the labor market. In N. Terleckyi (Ed.), *Household production and consumption*. New York: Columbia University Press.
Vincoli, J. W. (1994). *Basic guide to accident investigation and loss control*. New York: Wiley.