Fuzzy Logic Approach for Estimating Intangible Costs Related to Work Injuries

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Abstract

Estimating intangible costs related to work injuries based on fuzzy logic approach is a technique that attempts to formulize the nonlinear-multidimensional relationship between input-qualitative variables related to intangible costs of work injuries and the monetary value encountered with them. This technique approaches the problem from a unique standpoint; It reflects the individual's degree of believe of the un-sharp boundaries of influential input parameters and map them to a single and crisp value in terms of cost estimation of a particular hidden cost of investigation. In this research, a new method to estimate the intangible costs of work injuries based on fuzzy logic philosophy is proposed. The influence of the intangible costs on the overall performance is discussed.

Keywords: Intangible Costs, Work Injuries, Fuzzy Logic, Modeling.

1 Introduction

In today's competitive global economy, attempts to reduce costs encountered with manufacturing processes are a serious priority for most industries. The high increase in raw material and fuel costs and the dropping in sales rates stimulate companies to develop strategies to cut out expenses. Costs of work injuries have major contributions on the overall expenses. Therefore, new strategies should be adapted to minimize the contribution of work injuries on the total expenses. The apparent costs related to work injuries include the insurance premiums, medical, and indemnity costs. (Dorman 2000; EU-OSHA 2005; Miller et al 2002) Although, the unobserved costs of work injuries are usually disregarded, they have a significant impact on the total costs and thus worth investigations (EU-OSHA 1999). Work injuries may result in extra costs related to decline in co-worker integrity, morality, and virtuous behaviors. Also, hiring and training new or temporary employee increases the undesirable turn-over rate. Time lost from work, overtime, and the administrative time spent in accident's investigations will intensify the overhead costs. The costs of equipments damage or unsecured merchandise caused by work accident will add another unscheduled obstacle on organizations' budget. On the meanwhile, litigation expenses, legal penalties, citations, interrupted production schedules or any failure to fulfill customer commitments will reduce the competitive edge of the company and have a severe impact on the total costs. (Aldana 2001; EU-OSHA 2005; Foley et al 1995)

2 Costs of work injuries

In current research, cost of work injuries are classified as direct and indirect costs as shown in Table 1 and Table 2, respectively. (EU-OSHA 2009; Niven 2000; Leigh et al., 1997) Compensations, medical coverage, and rehabilitation expenses are examples of direct costs related to work injuries. It is clear that theses direct costs have close and diametric connections with work injuries. On the other hand, indirect costs are the implicit and inevitable expenses that are related to work injury in a devious way. Property damage, administrative costs, and legal expenses are typical examples of indirect cost of work injuries. To certain extend the sum of both the direct and indirect cost objects measures the overall costs of work injuries. (Weil 2001)

Table 1. The direct costs related to work injuries.

Table 2. The indirect cost related to work injuries.

3 Literature Review

Previous research was focused on the estimation of the cost of work injuries by using one of three primary methods: the human capital method, the friction method, and the willingness to pay method. (Amador-Rodezno 2005; Antonelli et al 2006; Behm et al 2004; Oxenburgh and Marlow, 2005).The human capital method suggests that the cost lost in production due to mortality or permanent disability is a multiplication of prospective discounted earning by the probability of living to that age. This approach is the most common approach used to estimate the cost of work injuries. However, this approach has two major limitations. The first one is that certain groups are assigned a higher value of impact than others according to their age, gender, etc. The second drawback is the use of full replacement costs independent of whether the worker was replaced or not.

Friction cost method considers the productivity costs only during the restoration period needed to return to initial production level. This approach covers the cost of short term disability and hiring or training a new employee (Koopmanschap et al., 1995; Ale et al. 2008). Determination of the duration period to return to the initial level of productivity is a major shortcoming of this approach. (Rice et al 1989; Currie et al 2000; Goeree et al., 1999).

The willingness to pay method considers the maximum amount that person would be willing to pay or sacrifice to mitigate or eliminate the probability of risk of injury. It

measures monetary the good choice instead of the bad choice. Usually, this will be conducted by a survey or the additional pay for high risk jobs. The drawback of this method is that the cost will be intensify and over estimated. (Rydlewska-Liszkowska 2005; Hirth et al 2000)

4 Tangible and Intangible costs

It is obvious that there is no specific and unique method could describe the cost of loosing pleasure or the cost of grief due to work injuries monetarily. Despite the impact of these costs on the organizations' performance, these kinds of costs usually ignored and mistreated. Accordingly, costs of work injuries should be classified as tangible costs and intangible costs. The tangible costs are those which have a common quantity or a tag value attached to cost objects. On other words, the cost objects of the tangible costs are well defined and their monetary values could be recognized directly during the accounting period. The costs of equipments' repair due to work accident represent an example of this type of costs. (Reville et al 2001; Hodgson and Meiners 1982).

The intangible costs are insubstantial and neither can be collected within the normal accounting system nor can they rely on the past or future payments or commitment to pay. The ground of intangible costs is flimsy and they measure the opportunity that is lost or sacrificed when the choice of action requires that an alternative course of action be given up. Thus, opportunity costs are not restricted nor constrained to monetary or financial costs. The real cost of productivity forgone or declined, lost time due to work accident, or lost of pleasure are few examples of intangible costs.

Estimating the intangible costs will give a significant judgment about the actual cost of any course of action when there is no explicit accounting system or determinant monetary price attached to the cost objects. Ignoring the intangible cost will result in illusions and false estimations of the true cost of work injuries.

Based on tangible and intangible expenses, the cost of work injuries could be formulated as:

$$C = \sum_{i=1}^{k} T_i + \sum_{j=1}^{m} I_j \qquad (1)$$

where;
C the total costs of work injuries,
T the tangible costs
I the intangible costs
k the set of all costs objects of tangible costs
m the set of all cost objects of intangible costs

The tangible costs could be classified as direct and indirect costs. The cost object of the direct or indirect cost should be determined to certain extend without any ambiguous. The

problem arise is how to estimate the uncertain intangible costs of work injuries. (Mrozek and Taylor, 2002)

5 Modeling Intangible Costs Based on Fuzzy Logic

Details of the intangible costs of work injuries should be accumulated to describe the entire system of all intangible costs objects. Based on these descriptions, intangible cost analysis based on fuzzy logic will evaluate the performance. These evolutions in most cases are qualitative. The intangible costs of work injuries are a function of multiple independent variables. As shown in Figure 1, the relationship between these independent variables and their values are interpreted and mapped to the output vector that describe the overall performance criteria related to the intangible costs of work injuries. Any cost object of the intangible costs set is a function of different quality variables. (Zadeh 1965)

Figure1. The basic concept of estimating intangible cost by using fuzzy logic approach

Let X represents the input space which is the input parameters or the bases of the cost objects related to a specific intangible cost. The intangible cost of a particular cost objects will be a nonlinear multiple input space variables function as follow:

$$I_j = f(X) \qquad j \in m \tag{2}$$

If the elements of the input space are denoted by x, a fuzzy set A in X is defined as a set of order pairs:

$$A = \{x, \psi_A(x) \mid x \in X\} \tag{3}$$

Where, ψ_A is the membership function of the input space elements x in the fuzzy set A which maps each element of input variable intangible cost's parameters X to a membership value. The membership function is a curve that maps the input universe multivalently to a membership value between 0 and 1 as depicted in Figure 2, (Zimmermann 2001; Sivanandam et al 2006; MATLAB 2009). The shapes of these functions are flexible and robust to accommodate the differences in tradition, culture, believes, and individual's point of view. (Zadeh 1965)

Figure 2. The membership function, ψ_A.

The relationship between input variables are based on some set of rules that link these variables with the output by logical statements. Fuzzy logic approach will blend the rules and associate those to a membership function that reflect the degree of believe. The rules have a degree of flexibility to tolerate imprecise or stochastic data. They are based on *if-then* statement which describes the relationship between the input space variable and the output space qualitatively. (Mitaim and Kosko 1998; Zimmermann 1987).

As mentioned earlier, the intangible cost could be modeled as a nonlinear with multi-dimension quality input variables. This will give the fuzzy logic approach the capability of estimating the hidden cost of work injuries qualitatively. Since the estimation of intangible costs is a matter of degree, fuzzy logic relates to classes of objects with un-sharp boundaries. The cost of suffering due to work injury is an example of output intangible cost with un-sharp boundaries that rely on but not limited to qualitative input variables such as the severity of injuries, age, and duration of pain. A weight factor can be added to each rule to reflect the magnitude of this rule on the total output variable. (Zimmermann 1987; Zadeh 1965; El-Nasr et al., 2000)

6 Determination of Intangible Costs

To estimate the intangible costs using fuzzy logic approach, the input space variables, the rules, and the output must be defined. The basic structure of this model approach is shown in Figure 3. (Sivanandam et al 2006)

Figure 3. Basic structure of intangible cost estimation based on fuzzy logic.

According to this model, the first step is to determine the degree to which the input crisp parameters belong to each of the appropriate fuzzy set via their membership functions. The output of this process will be a fuzzy degree of membership in the qualifying linguistic set between 0 and 1. Usually, the antecedent of the if-then rule statement has more than one

part (Mitaim and Kosko 1998; Martinez-Miranda et al 2002). The fuzzy logic operator will be applied to obtain one number that represents the results of the antecedent for that rule. The AND-statement can be represented as A & B = min (A, B), while the OR-statement can be represented as A or B = max (A, B), and the Not statement can be represented as Not A=1 – A. (MATLAB 2009).
Implication will apply in parallel for each rule. The output of the implication is a fuzzy set for each rule. The aggregation is process which combined the fuzzy sets for each rule into single fuzzy set. Therefore, the input of aggregation process is the output from implication for all rules.
The aggregated output fuzzy set is the input for the defuzification process. The output of this process is a single number. (Zimmermann 2001; Sivanandam et al 2006)

7 A Hypothetical Example

It is obvious that there is a strong relationship between productivity output, level of training and severity of injury. To demonstrate the proposed approach, the intangible cost of reduced productivity, R, due to work injuries will be assumed and defined as a function of two influential input variables: the severity of work injuries (x_1) and the level of experience (x_2) of the injured person. Let X represents the input space variables x_1 and x_2 respectively (MATLAB 2009). The reduced productivity will be represented as:

$$R = f(X) \tag{4}$$

The input variables x_1 and x_2 will be described qualitatively as fuzzy values of low, medium, and high. The membership functions that are associated with each qualitative input variables severity (x_1) and experience (x_2) are shown in Figure 4. These curves are chosen intentionally to reflect the degree of believe of theses quality input variables on scale from 0 to 10 and mapped out to a value from 0 to 1. All the input's membership functions are assumed to be a Gaussian type with standard deviation 1.5

Figure 4. The input variables: the severity degree, x_1, and experience level of work injuries, x_2, and their associated membership functions.

The output variable which represents the lost of productivity due to work injury and their membership functions is assumed to be in a triangular shape. As shown in Figure 5, the fuzzy values are very low, low, medium, high, and very high. The associated parameters of the membership functions are selected to be compatible with the input parameters.

Figure 5. The output lost of productivity and the memberships functions

The rules that link the input variables and their weights are defined as shown in Table 3:

Table 3. The if –then rules and their weights.

8 Results and Conclusions

The percentage of individual's productivity lost in work injury is a function of multiple variables of input parameters. On this hypothetical example, the lost of productivity is shown in Figure 6 as a function of the severity of injury and the level of experience of the injured person. Normally, this relationship is not linear and could not be generalized. It should reflect the degree of believes, the culture of the society, and the common laws.

Figure 6. The nonlinear relationship between productivity lost, level of experience, and the severity of work injury.

Fuzzy logic approach has the flexibility to accommodate these differences and to operate under uncertainty and unsharp boundaries. The input space is not limited and therefore this approach is capable to contain all the input parameters that influence the intangible costs of work injuries. The gravity of each rule and its effect on the decision can be modeled by a weight factor to emphasis the critical conditions. The influential input parameters of intangible costs could be adjusted at any time if the conditions are altered. This will give the fuzzy model approach of estimating the intangible costs of work injuries the credibility and the agility of estimations over the traditional methods.

9 References

Aldana, S., 2001. Financial impact of health promotion programs: A comprehensive review of the literature. Am. J. Health Promotion, 15: 296-320.
600811ja

Ale, B.J.M., H. Baksteen, L.J. Bellamy, A. Bloemhof and L. Goossens <I>et al</I>., 2008. Quantifying occupational risk: The development of an occupational risk model. Saf. Sci., 46: 176–185.
600814ja

Amador-Rodezno, R., 2005. An overview to CERSSO's self evaluation of the cost-benefit on the investment in occupational safety and health in the textile factories: A step by step methodology. J. Safety Res., 36: 215-229.
600819ja

Antonelli, A., M. Baker, A. McMahon and M. Wright, 2006. Six SME case studies that demonstrate the business benefit of effective management of occupational health and safety. Research Report 504. Health and Safety Executive.
34168an

Behm, M., A. Veltri and I.K. Kleinsorge, 2004. The cost of safety: Cost analysis model helps build business case for safety. Professional Safety, 49: 22-29.
600869ja
Currie, G., K.D. Kerfoot, C. Donaldson and C. Macarthur, 2000. Are cost of injury studies useful?. Injury Prevention, 6: 175-176.
600872ja
Dorman, P., 2000. The economics of safety, health and well-being at work: An overview. Focus Program on Safe Work, International Labour Organisation, The Evergreen State College, May.
34171an
El-Nasr, M., J. Yen and T. Ioerger, 2000. FLAME- Fuzzy Logic Adaptive Model of Emotions, Autonomous Agents and Multi-Agent Systems. Kluwer Academic Publishers, Netherlands, pp: 219-257.
62537b
EU-OSHA-European Agency for Safety and Health at Work, 2009. Occupational safety and health and economic performance in small and medium-sized enterprises: A review . Office for Official Publications of the European Communities, Luxembourg, ISBN-13: 978-92-9191-228-5

62540b
EU-OSHA-European Agency for Safety and Health at Work, 1999. Economic impact of occupational safety and health in the member states of the European Union. Office for Official Publications of the European Communities, Luxembourg,
62541b
EU-OSHA-European Agency for Safety and Health at Work, 2005. Effectiveness of economic incentives to improve occupational safety and health. Forum 14/EN.
34175an
Foley, G., J. Gale and L. Gavenlock, 1995. The cost of work-related injury and disease. J. Occupational Health Safety Austr. N. Z., 11: 171-194.
600934ja
Goeree, R., B.J. O'Brien, G. Blackhouse, K. Agro and P. Goering, 1999. The valuation of productivity costs due to premature mortality: A comparison of the human-capital and friction-cost methods for schizophrenia. Can. J. Psychiatry, 44: 455-463.
600939ja
Hirth, R.A., M.E. Chernew, E. Miller, A.M. Fendrick and W.G. Weissert, 2000. Willingness to pay for a quality-adjusted life year: In search of a standard. Med. Decision Making, 20: 332-342.
600944ja
Hodgson, T.A. and M.R. Meiners, 1982. Cost of illness methodology: A guide to current practices and procedures. Milbank Memorial Fund Q. Health Soc., 60: 429-462.
600949ja
Koopmanschap, M.A., F.F. Rutten, B.M. van Ineveld and L. van Roijen, 1995. The friction cost method for measuring indirect costs of disease. J. Health Econ, 14: 171-189.
600957ja

Leigh, J.P., S.B. Markowitz, M. Fahs, C. Shin and P.J. Landrigan, 1997. Occupational injury and illness in the United States. Estimates of costs, morbidity and mortality. Arch. Intern. Med., 157: 1557-1568.
600959ja
Martinez-Miranda, J., A. Aldea and R. Banares-Alcantara, 2002. A social agent model to simulate human behaviour. Proceedings of the 3rd Workshop on Agent-Based Simulation, Apr. 02, USA., pp: 18-23
21144con
MATLAB, 2009. MATLAB fuzzy logic toolbox help. The MathWorks, Inc. http://www.mathworks.com/access/helpdesk/help/toolbox/fuzzy/index.html.
34173an
Miller, P., P. Rossiter and D. Nuttall, 2002. Demonstrating the economic value of occupational health services. Occupational Med., 52: 477-483.
600961ja
Mitaim, S. and B. Kosko, 1998. Neural fuzzy agents for profile learning and adaptive object matching. Presence, 7: 617-637.
600964ja
Mrozek, J.R. and L.O. Taylor, 2002. What determines the value of life? A meta-analysis. J. Policy Anal. Manage., 21: 253-270.
600968ja
Niven, K., 2000. Economic principles in occupational health and safety. Occupational Health Rev., 88: 13-18.
600969ja
Oxenburgh, M. and P. Marlow, 2005. The productivity assessment tool: Computer-based cost benefit analysis model for the economic assessment of occupational health and safety interventions in the workplace. J. Safety Res., 36: 209-214.
600972ja
Reville, R.T., J. Bhattacharya and L.R.S. Weinstein, 2001. New methods and data sources for measuring economic consequences of workplace injuries. Am. J. Indus. Med., 40: 452-463.
600979ja

Rice, D.P., E.J. MacKenzie and A.S. Jones <I>et al</I>., 1989. Cost of injury in the United States: A report to Congress. San Francisco: Institute for Health and Aging, University of California; Injury Prevention Center, Johns Hopkins University
34185an
Rydlewska-Liszkowska, I., 2005. Models of economic evaluation of health and safety interventions at workplace. Med. Pr., 56: 411-418.
600993ja
Sivanandam, S.N., S. Sumathi and S.N. Deepa, 2006. Introduction to Fuzzy Logic using MATLAB. Springer, 2006.
31350b
Weil, D., 2001. Valuing the economic consequences of work injury and illness: A comparison of methods and findings. Am. J. Ind. Med., 40: 418-437.
11598992
Zadeh, L.A., 1965. Fuzzy Sets. Inform. Control, 8: 338-359.
31886ja

Zimmermann, H.J., 2001. Fuzzy Set Theory and its Applications, Fourth Edition, Kluwer, Boston.
2598b
Zimmermann, H.J., 1987. Fuzzy Sets in Pattern Recognition. Pattern Recognition Theory and Applications, Devijver, P.A. and J. Kittler (Eds.). Springer-Verlag, New York.
20587bc

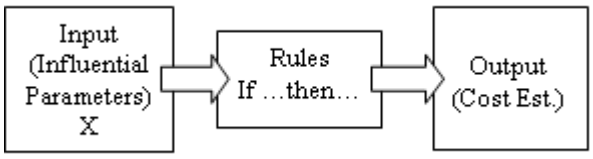

Figure1. The basic concept of estimating intangible cost by using fuzzy logic approach

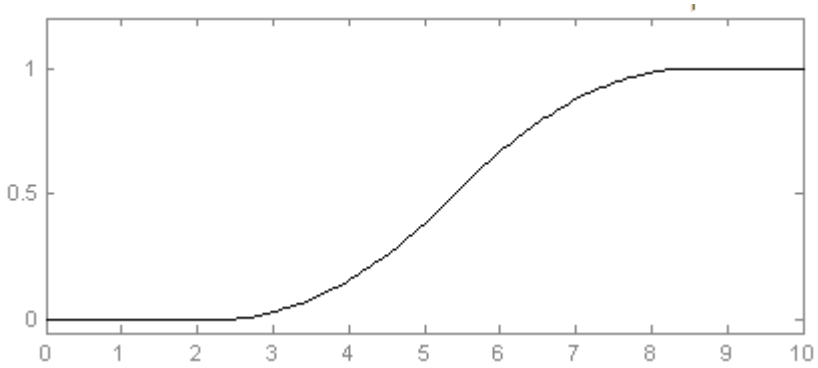

Figure 2. The membership function, ψ_A.

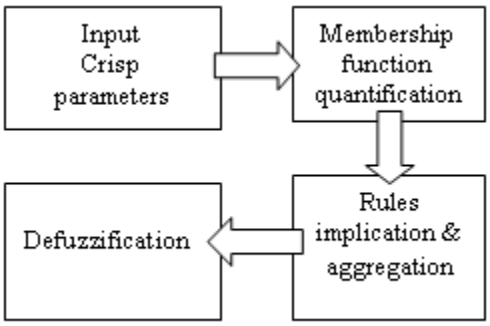

Figure 3. Basic structure of intangible cost estimation based on fuzzy logic.

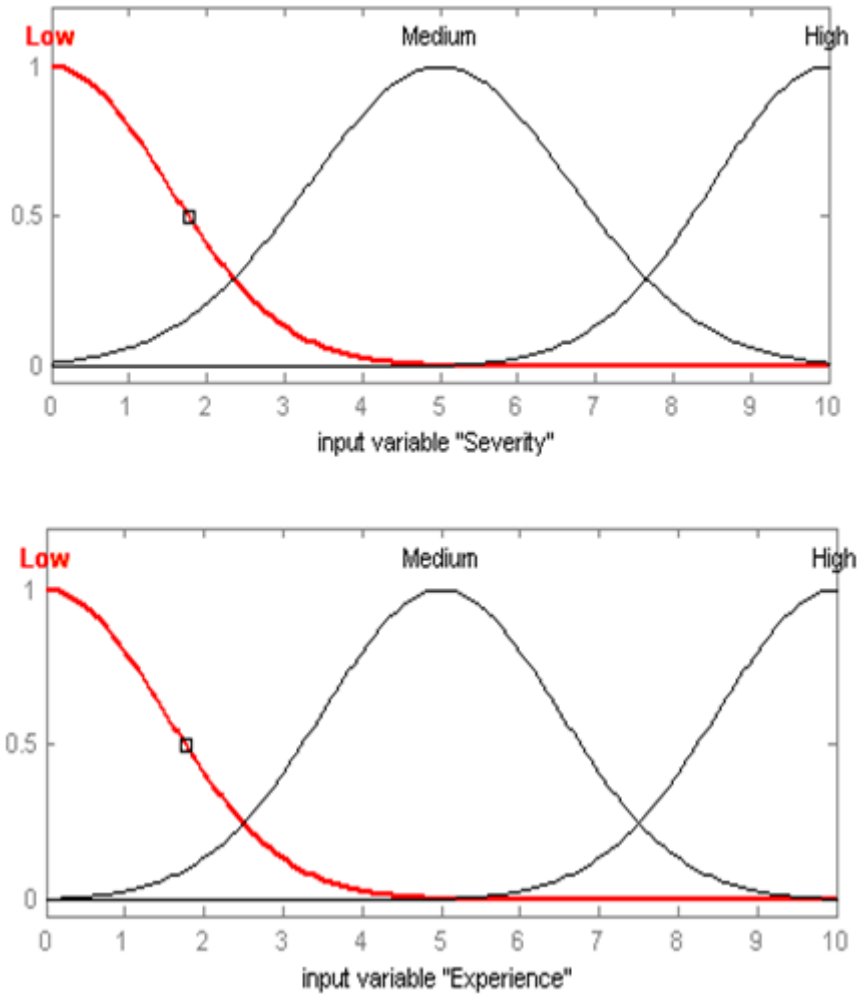

Figure 4. The input variables: the severity degree, x_1, and experience level of work injuries, x_2, and their associated membership functions.

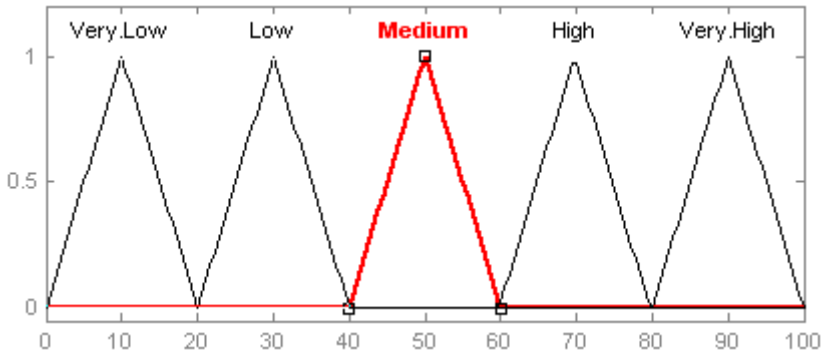

Figure 5. The output lost of productivity and the memberships functions

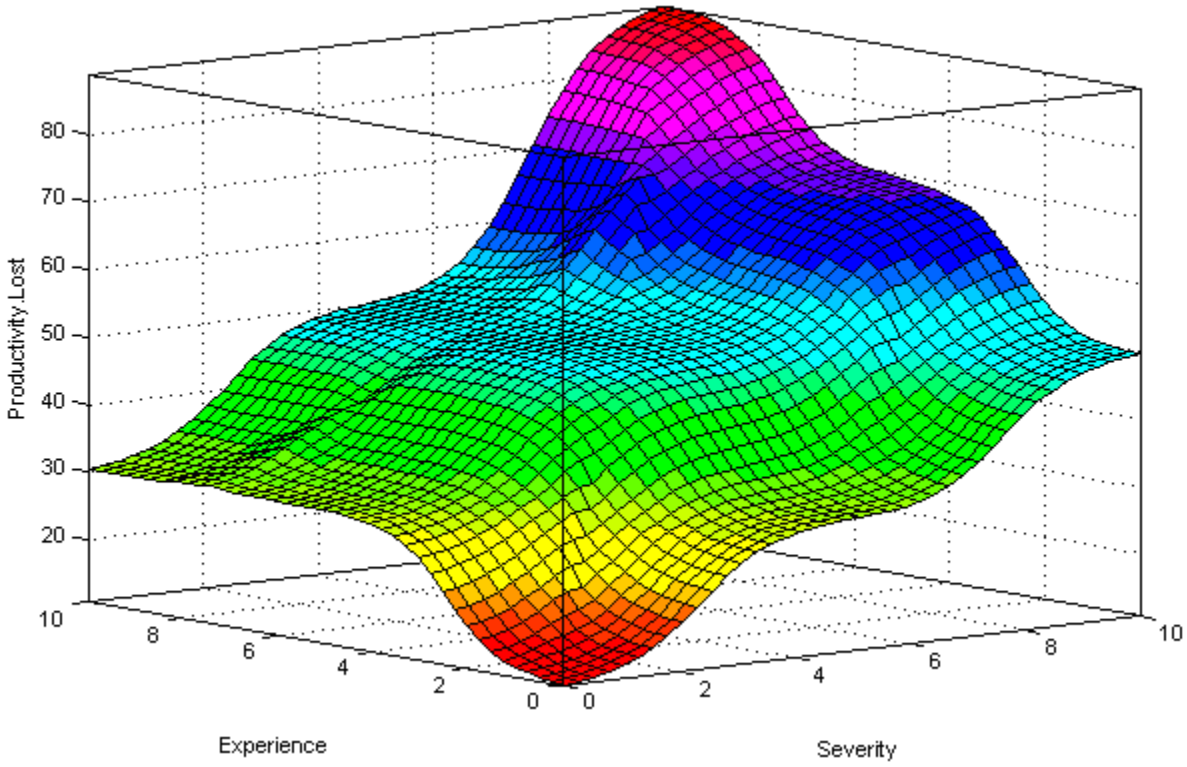

Figure 6. The nonlinear relationship between productivity lost, level of experience, and the severity of work injury.

Table 1. The direct costs related to work injuries.

Cost object	Description
Compensation, Medical Treatment, Rehabilitation	• Reimbursement, medical invoice, remedy, wage, supplements and continuation of benefits.

Table 2. The indirect cost related to work injuries.

Cost object	Description
Property, Equipment, and Material Damage	• Cleanup, repair, replacement, rental or salvage property • Material and product loss or rework
Administrative Costs	• Management effort: clean up, restoration, rescheduling, compliance, replacement hiring and training. • Follow up with injured employee including return to work or modified work. • Administrative effort in claims management, medical and personnel effort and public relations.
Productivity Costs	• Work interruption and scheduling inefficiencies. • Rescheduling and overtime costs. • Cost of learning curve of replacement employees. • Lost of productivity due to litigation. • Lost opportunity cost due to loss of use of equipment, processes, or skills of injured person. • Cost of alternate processes or contingency plan. • Customer Service costs such as out of stocks and delays in delivery.
Legal Costs	• Legal Counsel Fees • Expert Witness Fees • Fines or Equipment/process modifications • Settlements cost.

Table 3. The if –then rules and their weights.

	x_1	Logic Operator	x_2		R	Weight
If	H	&	H	then	VH	1
	H	&	M		H	1
	H	&	L		M	1
	M	&	H		M	1
	M	&	M		M	1
	M	&	L		L	1
	L	&	H		L	1
	L	&	M		L	1
	L	&	L		VL	1