

# **CRANE CABINS WITH INTEGRATED VISUAL SYSTEMS FOR THE DETECTION AND INTERPRETATION OF ENVIRONMENT - ECONOMIC APPRAISAL**

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*This paper analyses the economic feasibility of production and use of the new generation crane cabins of considerably lighter weight and stiff structure whose interior space necessary for the operator will be developed by using the methods of physical, cognitive and organizational ergonomics with the solved problem of visibility and which will allow higher productivity due to reduction of physical and psychological stress of the operator, as well as greater safety and security due to the integrated visual system. It is proved that the total economic benefit of the exploitation of the cabin in the overall exploitation period is significantly higher than the purchase price of the cabin, as well as that the internal rate of return is above the relevant average weighted interest rate and the payback period is less than three years. The analysed project of production and use of crane cabins with integrated visual systems for the detection and interpretation of environment is the project with low economic risk.*

*Key words: Economic feasibility, Cranes, Cabin, Integrity, Products, Operator*

## **INTRODUCTION**

As a result of the complicated and constantly changing nature of industrial and construction work, there are very high injury and fatality rates, where cranes contribute to as many as one-third of all fatalities and injuries resulting in permanent disability [01]. The Crane and Hoist Safety report - OSHA reported a death rate of 1.4 deaths per 1000 operators [06]. Human error is the cause of almost 60% of lifting operation related accidents [01]. It is not surprising since crane operators still work in ergonomically unadjusted surrounding with very high visual tension in stressful working conditions due to both physical stress (shocks, vibrations and accelerations), and psychological stress (the sway of the load, extremely low visibility of cranes, etc.). Additionally, the ever growing competitiveness in the international and/or national market makes further improvement in the management, effectiveness and efficiency of crane operations and crane systems absolutely essential. According to previous research results

[01,06, 05] a new solution for crane cabins is needed to solve the aforementioned problems is needed. The goal is to develop crane cabin as ergonomically adjusted, light weight and integrated visual systems for the detection and interpretation of environment.

## **TECHNICAL DESCRIPTION AND FEASIBILITY**

We propose the following: 1) To develop smaller and lighter ergonomically adjusted crane cabins with appropriate safety features using physical, cognitive and organizational ergonomics and modelling, and static and dynamic calculations using the finite element method; 2) To develop well designed integrated visual systems for the detection and interpretation of environment which will solve the operator's visibility problems; 3) To develop a simulation crane cabin, based on Virtual Reality technology, to replicate a real crane cabin together with the instrumentation and control of crane operations for the purposes of training and enhancing the cognitive abilities

necessary for the effective and efficient use of integrated vision systems, and 4) To develop a prototype remote control for cranes which will include a remote control console and associated tracking (sensory) and management information systems. The main innovative idea behind this project consists of synergetic contributions from the following entities as the main fields of development: a) The development of a model with the minimal dimensions of the cabin where the operator will be accommodated in an ergonomically adjusted way based on an anthropometric study; b) The development of a model for the cabin interior including well-designed controls and the control station layout according to the principles of ergonomics and biomechanics which will ensure good safety features, c) The further optimization of the cabin by designing a light weight cab supporting structure with the application of the finite element method (FEM) for the analysis of load distribution, membrane and bending stresses, strain energy and the distribution of kinetic and potential energy to groups of elements of cab structure; d) The development of integrated visual systems for the detection and interpretation of environment which will solve visibility problems; e) A Virtual Reality based simulation cabin, and f) A crane remote control prototype setup. The benefits of this project lie in offering solutions to the following problems: (i) lower productivity due to human-machine interface problems; (ii) large financial and other losses resulting from the direct and indirect costs of the accidents caused; (iii) damage to the materials as well as to the material handling equipment; (iv) the unnecessary cost of frequent repairs and consequent loss of production; (v) disturbance in material handling schedules and (vi) an increased work-load on the other equipment and their consequent quicker downtime and break down.

### **ECONOMIC APPRAISAL METHODOLOGY**

According to the Global Cranes, Lifting and Handling Equipment – Market Opportunities and Business Environment, Analyses and Forecasts to 2015 document produced by World Market Intelligence during the period 2006-2010, the consumption value of the global crane, lifting and handling equipment market grew at a CAGR of 2.76%. After witnessing a year of production and consumption decline due to low demand, the market recovered in 2010 to record production growth of 5.9% and consumption growth of 4.7%.

Whilst South America experienced the fastest growth in consumption value during the review period, Asia-Pacific and Europe made the highest contributions to market consumption value in 2010. In terms of construction equipment from emerging nations to support infrastructural and mining investments, global cranes, lifting and handling equipment consumption is expected to record a CAGR of 10.75% in the forecast period - 2015. The European market has experienced a constant and the largest growth, amounting to 46% in 2000, in contrast to 15% in America and 11% in the rest of the world. A European crane cabins market is envisaged in this project as this is the area with the lowest transportation costs, thus the highest market growth is expected in this region.

For the assessment of economic feasibility of development, production and use of crane cabins, in practice the most commonly used approach is cost-benefit (CB) framework. Economic feasibility assessment through the cost-benefit framework can generally be used in the two assumed scenarios:

- development, production and sale of a new generation of crane cabins (producer point of view)
- use /purchase of the above type of crane cabins by the crane owners /lessors.

Economic and financial feasibility in the first assumed scenario foresees defining the standard parameters of the assessment from the aspect of a cabin producer (owner of the crane cabin factory, shareholders, potential creditors) and the overall economy [3]. This approach requires developing complete tables of financial and economic flows, necessary for the calculation of the selection criteria (FNPV, FIRR, ENPV, EIRR, pay-back period, BCR).

The second approach refers to an assessment of economic feasibility of investing into acquisition of a new generation of crane cabins and/or comparison of such investments (initial investment costs) and discounted additional effects (savings) in the crane exploitation over the entire (remaining) lifetime. Thus developed net flow serves as a basis for developing the quantitative parameters for the justification of investment and/or purchase of the new generation crane cabins from the aspect of the crane owner or user and from the aspect of the entire economy (NPV, IRR, BCR, pay-back period). For creating an economic net flow related to a new crane cabin, it is necessary to identify and quantify relevant costs and effects. [08, 03].

## Costs

In the standard terminology that refers to project analysis, acquisition (purchase price) of the new generation of crane cabin can be seen as an initial investment cost. In the competitive circumstances, purchase price is nearly equal to the marginal production cost, increased by transport, insurance and trade margin. The cost of manufacturing a cabin should include materials, labour and energy costs, as well as a portion of dependent fixed costs. In addition to the costs included in the purchase price ( $I_0$ ), it is necessary to assemble and test the crane cabin, ensure training for a crane operator, but also disassemble the existing cabin if it is already existed on the crane ( $I_1$ ). Initial investment costs, required for the economic assessment of the project of using the new generation crane cabins, would represent a sum of the above-mentioned costs ( $I_0 + I_1$ ).

## Benefits

The exploitation of the new generation of crane cabins has direct and indirect positive effects from the aspect of the owner or user of the crane, but also positive effects on the overall economy. Direct positive effects from the point of view of the crane owner are primarily appeared through increase in productivity of the crane use. The cabin with integrated visual systems for the detection and interpretation of environment allows the crane operator to perform work operations faster. Savings of time at one duty allows the crane owner to engage the crane at another job without any additional exploitation costs. Reduction of the annual crane exploitation costs due to the assembly of the new crane cabin, which allows saving of time in performing work operations ( $\Delta t$ ) represents benefit from the aspect of the crane owner. As the exploitation costs depend on the time of the crane operation ( $t$ ), for the calculation purposes the positive effect for the crane owner represents a product of the sum of all exploitation costs and weight of the average time saving in performing operations ( $\sum CE_t \cdot \rho_t$ ).

The annual crane exploitation costs can be decomposed to the costs of depreciation (capital recovery), costs of maintenance and repairs, as well as insurance and registration costs. Formally, these costs can be presented as follows:

$$\sum CE_t = PC * PMT_n^i + MC_t + RC_t + IC_t \quad (1)$$

where PC represents a purchase value of the crane,  $PMT_n^i$  stands for capital recovery factor for the specific exploitation lifespan of the crane ( $n$ ) and interest rate ( $i$ ). Depreciation of the crane is observed as depreciation of debt and/or future value of equal annual repayments of the amount invested in the purchase of the crane.

Weight of the average time saving is determined as a relative ratio of the sum of differences in time of the operations performed by the crane without the new generation cabin and the time of operations with the new cabin and the total time of operations without the cabin with the integrated visual crane management system:

$$\rho_t = \frac{\sum_j^N (T_j^1 - T_j^2)}{\sum_j^N T_j^1} \quad (2)$$

where  $\rho_t$  represents weight of the average reduction in time of operation of the crane with the new cabin,  $T_j^1$  time of operation ( $j$ ) without the cabin with the integrated visual system for detection and  $T_j^2$  stands for time of operation ( $j$ ) with the new generation crane cabin.

The following direct benefit of installing the new generation crane cabins is reduction in labour costs. If we assume that the number of workers and labour cost per hour remain the same, operation time reduction allows the worker to perform in such time reduction an additional work that is beneficial for the crane owner. Accordingly, time reduction of the operations ( $\rho t$ ) which the crane achieves due to the use of the new generation cabins represents a weight for calculation of the annual savings in labour costs ( $LSC_t$ ) as a product of the number of workers, cost of labour per hour and number of working hours of the crane:

$$LSC_t = n * h_t * w_h * \rho_t \quad (3)$$

where  $LSC_t$  represents savings of labour costs in a year ( $t$ ),  $n$  stands for a number of crane operators,  $h_t$  number of effective working hours of the crane in a year ( $t$ ),  $w_h$  average value of the working hour and  $\rho_t$  is a weight of average savings of time of the crane operation in a year ( $t$ ).

By installing the new generation crane cabin, incidence of professional diseases and injuries of crane operators is reduced. This positive effect can be quantified through reduction of number of

working hours which the crane operator spends on a sick leave, during which period a new worker must be hired. This saving can be quantified as a product of the number of workers, number of hours lost due to the crane operator's absence, labour cost per hour and average weight of time reduction of the crane operations:

$$LSDC_t = n * Dh_t * w_h * \rho_t \quad (4)$$

where  $LSDC_t$  represents annual savings in labour costs while the crane operator is on a sick leave,  $n$  a number of crane operators,  $Dh_t$  number of working hours lost due to sick leaves,  $w_h$  represents a cost of the working hour and  $\rho_t$  weight of average time saving of the crane operation in a year (t).

Thanks to a better visibility, the use of the new crane cabin reduces a number of breakdowns and slows down wear and tear of the crane mobile parts and/or reduces the costs of crane maintenance and repairs. This positive effect is determined as a product of the crane value and difference in the relative annual maintenance and repair costs:

$$MRSC_t = PC * \left[ \frac{MRC_t^1}{PC} - \frac{MRC_t^2}{PC} \right] \quad (5)$$

where  $MRSC_t$  represents savings on the annual costs for maintenance and repairs of the crane,  $PC$  is a purchase value of the crane,  $MRC_t^1$  is the value of the annual costs for maintenance and repairs of the crane without crane cabin with visual system and  $MRC_t^2$  is a value of the annual costs for maintenance and repairs of the crane with the new generation crane cabin.

Through a more efficient use of the crane, the new generation crane cabin is supposed to extend the assumed crane exploitation lifespan. Extension of the crane exploitation lifespan brings additional benefits through reduction of annual depreciation (recapitalisation) costs of the crane which is quantitatively determined as the difference between recapitalised annual write-offs and the lifetime of the crane (n) without the new generation crane cabin and recapitalised annual write-offs with the extended crane exploitation lifespan (n+m):

$$ELSC_t = PC * PMT_n^i - PC * PMT_{n+m}^i \quad (6)$$

where  $ELSC_t$  represents annual savings on depreciation write-offs,  $PC$  purchase value of the crane,  $PMT_n^i$  capital recovery factor with the assumed exploitation lifespan without the new crane cabin (n) with appropriate interest rate (i), whereas  $PMT_{n+m}^i$  represents a capital recovery factor with the extended exploitation lifespan (n+m) due to the use of the new crane cabin with appropriate interest rate (i).

### ECONOMIC APPRAISAL CRITERIA

For the assessment of economic feasibility of the crane cabin with integrated visual systems for the detection and interpretation of environment, the following standard cost benefit criteria are defined: net present value, internal rate of return, cost - benefit ratio and payback period on investment. Net present value (NPV) of an investment in the new generation crane cabin represents the difference between the sum of initial investment costs and the sum of discounted savings over the entire lifetime of the crane, whereby such savings are resulting from the use of the new crane cabin:

$$NPV = -(I_0 + I_1) + \sum_t^{n+m} \frac{(CE_t + LSC_t + LSDC_t + MRSC_t + ELSC_t)}{(1+i)^t} \quad (7)$$

where  $NPV$  represents net present value of savings on costs of the crane exploitation achieved by the crane cabin with the integrated visual system over the crane lifetime (n+m) and (i) represents relevant discount rate. Based on this criterion, use of the new crane cabin is acceptable if the net present value is positive.

Internal rate of return ( $IRR$ ) of the investment in acquisition of the new crane cabin is the value of discount rate which equalize the difference of the initial purchase costs of the new crane cabin and the present value of the total savings in operating costs with zero. For a project to be economically justified, this rate should be above the average weighted interest rate. [02, 07].

Cost benefit ratio is a quotient of the total net savings of the crane exploitation and the purchase costs, assembly costs and training costs for the work in that cabin. According to this criterion, purchase of the crane cabin will be economically acceptable if this ratio is greater than one.

### ECONOMIC APPRAISAL RESULTS

For the assessment of the economic feasibility of the new generation crane cabin purchase, we

used the data referring to the bridge crane cabin. Table 1. provides the estimated data and, by using equtions from (1) to (7), calculated values referring to the costs of purchase and savings during the exploitation of the new crane cabin.

Table 1: Economic cost - benefit appraisal inputs

Variables	Values (Euros, %.)
Cabin manufacturing costs (costs of materials, labour, energy - $I_0$ )	20000 Eur
Costs of assembly, testing, crane operator training and disassembly of the existing cabin if it is already fitted on the crane ( $I_1$ )	1500 Eur
Benefits ( Savings)	
Savings in time of operations /cycle reduction / ( $\rho_t$ )	10 % (8-12%)
Purchase price of the crane	268000 Eur (20000-500000)
Annual savings on labour costs ( $LSC_t$ )	1440 Eur
Annual savings due to reduced incidence of professional diseases and injuries of crane operators ( $LSCt$ )	400 Eur
Reduction of the crane maintenance and repair costs ( $LSDCt$ )	4025 Eur
Savings due to the extended exploitation lifespan (from 15 to 18 years) ( $ELSCt$ )	1828 Eur

By using the expression (7), we estimated empirically net present value of the net effect of the purchase and use of the new generation crane cabin. Net present value as a synthetic measure of absolute economic viability is in the first step calculated on the basis of the best estimates values of variables. Those values are given in Table 1. Net present value is, at the discount rate of 10%, Eur 68350. The total economic benefit of the exploitation of the cabin in the overall exploitation period is higher than the purchase price of the cabin and according to this criterion, the project of installing the new generation cabin is economically viable. Internal rate of return as a relative measure of economic acceptability of the purchase and exploitation of the new crane cabin is significantly above the relevant average weighted interest rate and is equal to 34.30%, which implies high economic profitability of the investment. Annual savings which are made in the operation of the crane managed from the new generation cabin are Eur 13770 which shows

that the payback period is slightly less than three years. As these are estimated input values applied in the calculation of the relevant criteria for the assessment of acceptability, we used sensitivity and risk analysis to test the robustness of the obtained results.

Table 2: Sensitivity analysis

Change (%)	NPV		IRR(%)	
	+10	-10	+10	-10
Purchase value of the crane	77415	59273	37.31	31.26
Cabin price	64708	71980	31.11	38.17
Dh (savings in working hours )	68648	68040	34.4	34.19

Sensitivity analysis shows relative stability of results as the change of the selected critical variables in the range ( $\pm 10\%$ ) does not significantly influence the value of the criteria for the assessment of the economic viability of purchase and use of the new generation crane cabin. In risk analysis, we modelled five critical uncertain variables (cycle reduction, purchase price of the crane, cabin price, price of the working hour of a crane operator, number of working hours lost due to sick leaves and crane maintenance costs) by triangle probability distribution. Figure 1. gives an overview of simulation results (Hypercube sampling).

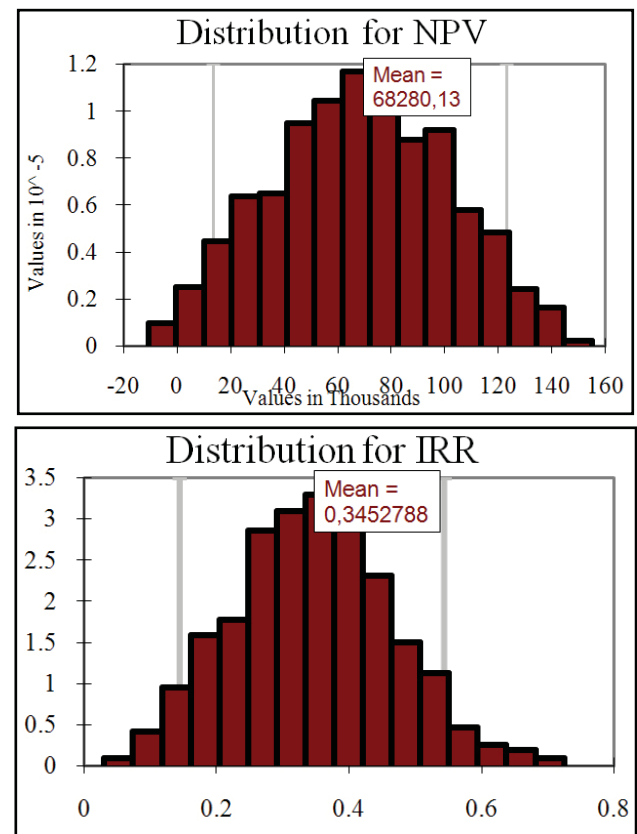


Figure 1: Distribution of the results

Net present value varies in the range from - 16123,6 Eur to 162144 Eur and the internal rate of return ranges from 3% to 72.4%. Probabilities for negative net present values and for internal rates of return below average weighted reference interest rate (10%) are very low. The results of the analysis show that the project of purchase and use of the crane cabin with integrated visual systems for the detection and interpretation of environment is the project with low economic risk.

### CONCLUSION

Techno-economic analysis of the project shows that the total economic benefit in the overall exploitation period is significantly higher than the purchase price of the cabin and according to this criterion the project of installing the new generation cabin is economically viable. Internal rate of return is above the average weighted interest rate, which implies high economic profitability of the investment. Annual savings made in the operation of the crane which is managed from the new generation cabin have the payback period of less than 3 years. The analyzed project of production and use of crane cabins with integrated visual systems for the detection and interpretation of environment is the project with low economic risk.

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