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CRANE CABINS' SAFETY AND ERGONOMICS CHARACTERISTICS EVALUATION BASED ON SWEDEN PORT DATA

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Abstract. *This paper presents an evaluation of crane cabins safety and ergonomics characteristics. It is based on previous research data collected for benchmarking analysis for crane cabins operating in one port in Sweden. Six crane cabin types are examined regarding eight characteristic divided in three groups: operator-control devices interaction, safety and anthropometric adjustment according to needs weighting data. Analysis of those data was conducted using indexes of characteristics performances, as well as Pareto analysis and final comparison. Taking into account all examined crane cabins only 52.5% of operator- control devices interaction, 75% of safety and 60% of anthropometric adjustment issues are satisfied in current designs.*

Key words: *crane cabin, operator-control devices interaction, safety, anthropometric adjustment, Pareto analysis, crane indexes of performance*

1. INTRODUCTION

Till today there is not large extent of research in the field of crane cabins convenience to the operator. One of rare research is the ergonomics field is conducted in steel plant in India on overhead crane showing large number of musculoskeletal disorders due to awkward work postures and insufficient vision angle [4]. Another study, which is in great extent connected to the subject of this paper was conducted in Sweden and they propose more user/friendly design [1]. The third research is based on anthropometric characteristic analysis to improve safety and prevent crane related fatalities and injuries [7]. Other authors mainly identify basic or individual characteristics of crane cabins without adequate analysis [2,3] such as sitting, visibility and noise issues, the existence of fire extinguishers, labeling the symbols, accessibility to cabin etc. [4,5,6]. In recent years slight shift is made toward serious research in order to design crane cabins with better ergonomic and safety characteristic which are economically viable [7, 8, 9]. However, the importance of studying of this problem greatly exceeds the number of published papers. Back and lower limb disorders occur very often to crane operators [10] and almost 30% of them feels extremely uncomfortable [7,11]. In construction and maintenance sectors cranes contribute to one-third of all fatalities, while large numbers of injuries and deaths is also encountered in transportation, manufacturing and warehousing industry sectors [7,12].

According to evident need this paper describes continuation of research on evaluation of crane cabin characteristics that operate in one Sweden port. It is based on benchmarking research data of Nordin and Olson [1] which is conducted in 2008. Results of their research are analyzed by Pareto method in order to obtain more precise data important for future crane cabins' design.

Table 1. Modified benchmarking table with grading criteria [1]

		characteristics	grading criteria	Lulea port	Liebherr	Krupp (LMG)	MHI	Tsuji	MacGreg or GLB
1	USI	Understandable signals	5	4	4	2	1	1	4
2	USY	Understandable symbols	4	1	4	1	1	2	4
3	SCD	See the content of the display	4	4	3	1	1	1	2
4	SCC	See the cargo, wharf and closest surrounding	5	4	3	4	1	3	3
5	FIC	Fixed items in cabin	4	3	4	4	4	3	4
6	RSP	Robust and steady parts	4	4	4	3	3	3	4
7	LEI	Logical and ergonomically correct placement of indicators and regulators	5	4	2	2	1	1	2
8	AWP	Adjustable work posture	5	5	2	4	1	2	2

Basic table from Nordin and Olson [1] for benchmarking (Table 1) was the starting point of this research. Semi-structured interviews with experienced crane operators and design according to [1] have shown that the following needs have to be satisfied to fulfill ergonomics and safety features: (1) the operator must see the cargo, wharf and closest surrounding (2) the operator must understand signals and symbols in cabin (3) the operator has the need to see the display (4) all parts in cabin must be robust and steady due to often careless behavior of operators (5) the placement of indicators and regulators must be logical and ergonomically correct (6) the operator has the need for adjustable work posture and (7) there is a need to have all items fixed in cabin due to risk of theft.

As shown in table 1. this research is based on examination of eight criteria on six different crane cabins' design solutions. It is presumed that Lulea port cranes have the same cabins for all cranes regardless crane manufacturer or crane characteristics [1]. Grading criteria are based on Likert scales 1 to 4 and 1 to 5 depending of examined characteristic, where 1 represents that examined characteristics doesn't fulfill the operators' needs for required characteristics, while 4 or 5 represent that it fulfills all desired characteristic criteria.

Further distribution of characteristics (Table 1) is conducted by dividing them in three major groups [1]:

- operator- control devices interaction (Table 1, characteristics 1-3),
- safety (Table 1, characteristics 4 and 5) and anthropometric adjustment (Table 1, characteristics 6-8).

2. METHODOLOGY

2.1. Measurement of index of performance of characteristics

Purpose of this analysis includes comparison between characteristics, impacts of individual characteristics on types of crane cabins, as well as overall appraisal of characteristics of different crane cabin types and appraisal from group types point of view. In order to compare different types of crane cabins (Table 1), scores obtained by Likert scale were transformed and equalized by introduction of index of performance *IP* and crane index of performance *CIP*.

Index of performance of characteristics can be defined as:

$$IP_{ij} = g_{ij} \big/ \max\left(c_j\right) \qquad (1)$$

where IP_{ij} is the index of the single characteristic (i=1...6) for individual cranes (j=1...8) from Table 1, g_{ij} is grade for crane characteristics, while c_j, is maximum value of Likert scale for observed characteristic.

Crane index of performance *CIP* is the sum of individual values of *IP* (1) for certain crane, i.e.

$$CIP_i = \sum_{j=1}^{8} IP_j, \mathrm{i} = 1,...,6 \qquad (2)$$

where CIP_i is one of the cranes i=1,..,6.

Those results are presented in Table 2.

Table 2. Values of IP and CIP for observed cranes

			Lulea port	Liebherr	Mac Gregor	Krupp	Tsuji	MHI
1	USI	Understandable signals	0.8	0.8	0.8	0.4	0.2	0.2
2	USY	Understandable symbols	0.25	1	1	0.25	0.5	0.25
3	SCD	See the content of the display	1	0.75	0.5	0.25	0.25	0.25
4	SCC	See the cargo, wharf and closest surrounding	0.8	0.6	0.6	0.8	0.6	0.2
5	FIC	Fixed items in cabin	0.75	1	1	1	0.75	1
6	RSP	Robust and steady parts	1	1	1	0.75	0.75	0.75
7	LEI	Logical and ergonomically correct placement of indicators and regulators	0.8	0.4	0.4	0.4	0.2	0.2
8	AWP	Adjustable work posture	1	0.4	0.4	0.8	0.4	0.2
		CIP	6.4	5.95	5.7	4.65	3.65	3.05

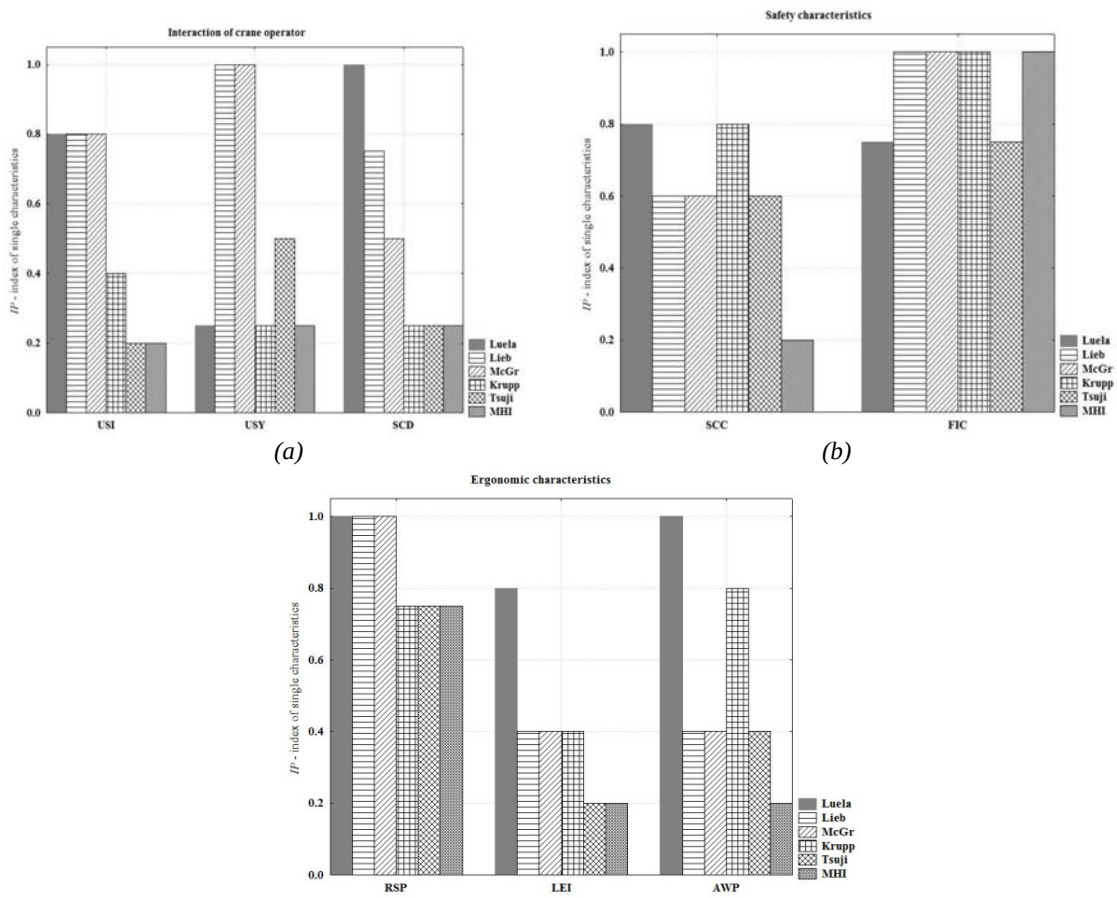
Based on examined criteria it can be concluded that crane cabins with best performances according to needs weighting are found at Lulea port (6.4), followed by cabins produced by Liebherr and MacGregor (5.95 and 5.95), while smallest CIP has MHI crane cabin (3.05). It can be also noticed that sums for all cabins show that only fixed items in cabin and robust and steady parts have marks above 5 of 6, that means that all other characteristics could be improved. Values of IP and CIP based on group characteristics: operator- control devices interaction, safety and anthropometric adjustment, are presented in Table 3.

From Table 3 it could be concluded that best interaction between control devices and crane operator has Liebherr crane cabin (2.55), following by MacGregor and Lulea port cabins (2.3 and 2.05). They are in the upper third of measurement scale while for the rest of examined crane cabins IP is significantly smaller. Regarding safety

characteristics (Table 3) Krupp crane cabin has the best safety characteristics (1.8), followed by Liebherr and MacGregor cabins (1.6). As for anthropometric adjustment characteristics, the best results are obtained by crane cabins from Lulea port (2.8), followed by Krupp (1.95) and Liebherr and MacGregor (1.8). Only Lulea port cabins' anthropometric adjustment characteristics are on the upper third of measurement scale also with maximum estimate of CIP for surveyed characteristics. Results from Table 3 are presented on Figure 1.

Table 3. Values of IP for group characteristics - interaction, safety and ergonomics

	characteristics by group	Lulea port	Liebherr	Mac Gregor	Krupp	Tsuji	MHI
ICO	operator- control devices interaction	2.05	2.55	2.3	0.9	0.95	0.7
SA	safety	1.55	1.6	1.6	1.8	1.35	1.2
ER	anthropometric adjustment	2.8	1.8	1.8	1.95	1.35	1.15
	CIP	**6.4**	**5.95**	**5.7**	**4.65**	**3.65**	**3.05**



(a) *(b)* *(c)*

Figure 1. Measured characteristic for interaction between crane operator and control devices (a), safety (b) and anthropometric adjustment (c)

2.2. Pareto analysis

Influence of observed crane cabin characteristics is further conducted using Pareto analysis. In this case all characteristics are observed equally, regardless on type, starting from the characteristic that is least good.

Pareto analysis for crane cabins in Luela port is presented at Figure 2.

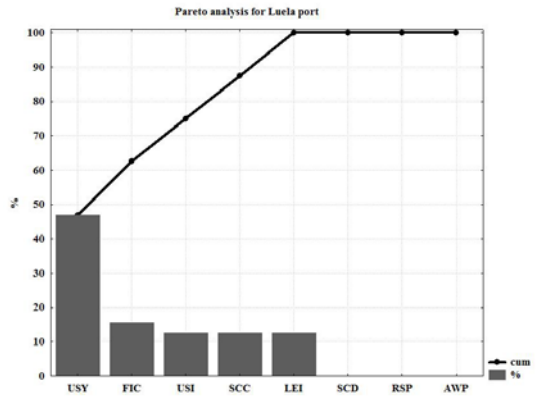


Figure 2. Pareto analysis for characteristics of crane cabins for Lulea port

Analysis of data for Lulea port crane cabins indicates that critical characteristic is symbols understanding with participation of 46.88%. Fixed item in cabin amount 15.63% followed by understandable signals or seeing the cargo, wharf and closest surrounding or placement of indicators with 12.5%. Mentioned characteristics represent 75% of problems in Lulea port crane cabins.
Liebherr crane cabin characteristics are expressed by Pareto graph as shown at Figure 3.

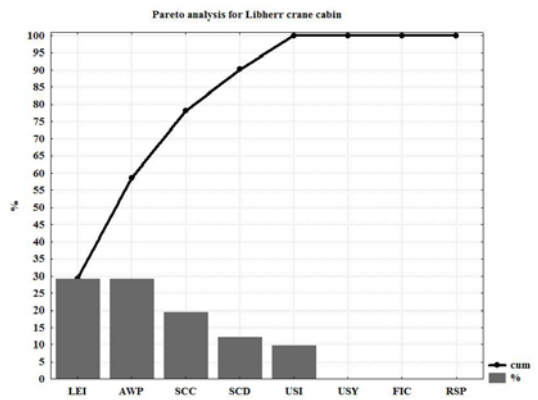


Figure 3. Pareto analysis for characteristics of Liebherr crane cabin

Majority of influence on Liebherr's crane cabin characteristics (80%) have placement of indicators and regulators and adjustable work posture with 29.67% each and seeing cargo, wharf and closest surroundings with 19.51% of influence.
For MacGregor's crane cabin characteristics Pareto graph is shown at Figure 4.

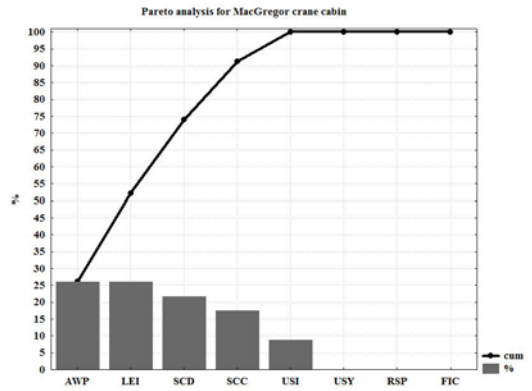


Figure 4. Pareto analysis for characteristics for MacGregor type of crane cabin

Influential characteristics of MacGregor crane cabin are adjustable work posture and placement of indicators and regulators with influence of 26.09% each, while visibility of content of display has an influence that amounts 21.74%. Those characteristics cover 73.92% problems in MacGregor type of crane cabin. If see cargo, wharf and closest surrounding is included with 17.39% of influence, than 91.31% of problems are covered.
Rest of observed types of crane cabins, i.e. Krupp, Tsuji and MHI are described together since their crane index of performance is significantly lower than above described types (Table 2). For Krupp crane cabin characteristics Pareto graph is shown at Figure 5, for Tsuji at Figure 6 and for MHI at Figure 7.

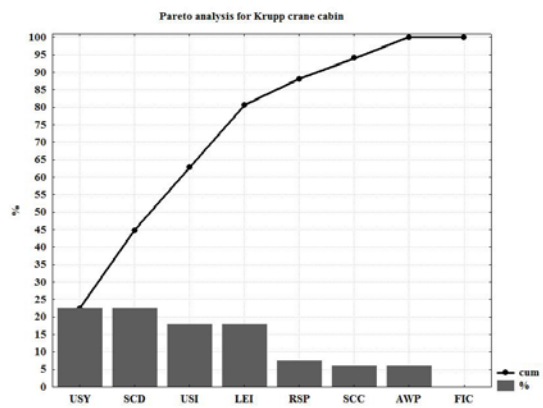


Figure 5. Pareto analysis for characteristics for Krupp type of crane cabin

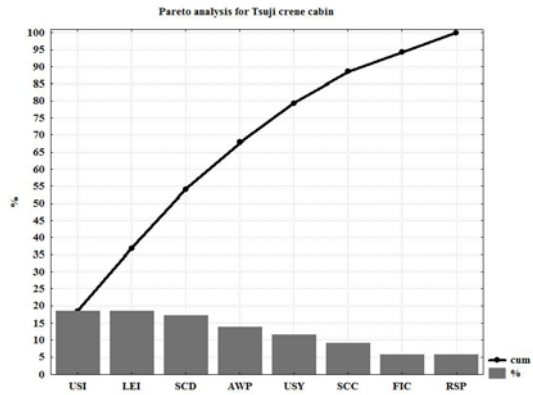


Figure 6. Pareto analysis for characteristics for Tsuji type of crane cabin

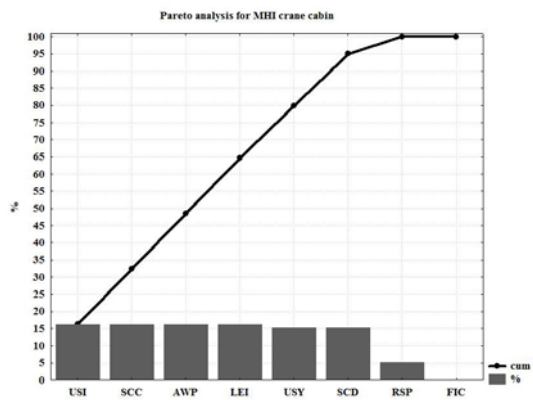


Figure 7. Pareto analysis for characteristics for MHI type of crane cabin

Krupp crane cabins have four influential characteristic, while Tsuji and MHI have 5 influential characteristics with 75% of influence.

2.3. Index of unsuitability

Beside Pareto analysis of characteristics, overall comparison was conducted using index of unsuitability of crane types.

Let index of unsuitability *IU* be

$$IUC_{ij} = 1 - IP_{ij}, i = 1,...,8, j = 1,...,6 \qquad (3)$$

with overall index of unsuitability of crane cabin characteristic based on (3)

$$UCIP_j = \sum_j^8 IUC_{ij}, i = 1,...,8, j = 1,...,6 \qquad (4)$$

$UCIP_i$, values obtained from (4) for all crane cabins are shown at Figure 8.

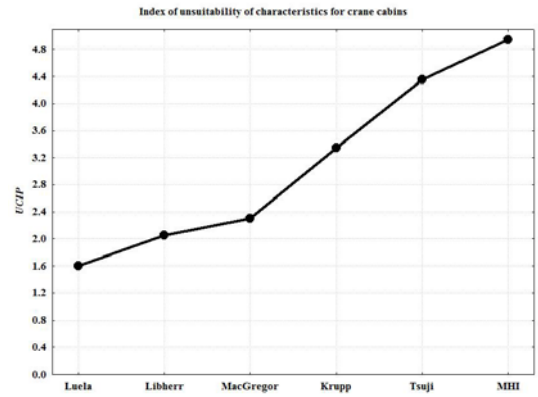


Figure 8. Indexes of unsuitability for considered crane types

3. CONCLUSIONS

Conducted analysis of the considered crane cabins and their characteristics according to operators' needs satisfaction given in [1] and according to analysis done in this paper leads to following conclusions:

- Taking into account all crane cabins only 52.5% of operator- control devices interaction, 75% of safety and 60% of anthropometric adjustment issues are satisfied in current designs.
- It is evident from Figure 8 that even the best rated Lulea cabins still have a room for 20% improvement, while MHI cabins have unsuitability that amounts 62.5%.
- Best characteristics have crane cabins at Lulea port and they are followed by Liebherr and MacGregor producers.
- Crane cabins at Lulea port and from Liebherr and MacGregor producers have significantly better characteristics than Krupp, Tsuji and MHI crane cabins regarding considered safety and ergonomics characteristics.
- Main problems for Lulea port crane cabins are in the fields of interaction between crane operator and controls followed by safety characteristics.
- Liebherr and MacGregor crane cabins could be improved by better placement of indicators and regulators and adjustable work posture, followed by the solution of visual problems of operator.

It is evident that contemporary crane cabins designs still do not satisfy operator needs in the fields of both safety and ergonomics and according to that future research are expected in those aims.

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