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Possibilities of Inadequate Physical Load Reduction by Ergonomic Rationalization of Working Environment

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Abstract

'Human' is the most important element in the working system: human - machine - environment. It is necessary to ensure the good health condition of workers for continuous production processes. This article is focused on the possibilities of inadequate physical load reduction by partial ergonomic rationalization of working environment - warehouse of building materials. This problem is analysed by using the Key Indicator Method (KIM). This method immediately determines the affecting physical load. Constituent optimization models of the working environment are suggested for reduction by software. The presented method of inadequate physical load reduction is applicable not only in the construction industry but also in engineering.

Keywords: Ergonomic rationalization, Key Indicator Method, physical load, Sketchup Pro, working environment

Introduction

Human activity creates a load, to a certain extent, for humans. Excessive working load causes the reduction of working performance and physical energy, and the aggravation of worker mental state [1]. Load can be subdivided into 3 categories - physical, mental, and sensory [2,3]. These 3 kinds of load can be further categorised into 4 basic groups - low, optimal, high, and inadequate load. The physical load classification is more easily made, because it is a quantifiable parameter [4,5].

Physical load emerges in workers in excessive load effects on muscles. This load is possible to divide into 2 categories - dynamic (muscle shortens, stretches) and static (change of internal muscle tension) [6]. The appropriate method to use to analyse and evaluate is determined by the kind of physical load. They are known 3 types of evaluation of physical load [7]:

- Direct methods - evaluation of quantity and size of stressors;
- Indirect methods - evaluation of organism frequency; and
- Special methods - evaluation by form, estimates, standards and tables.

Each of the above-mentioned methods is a tool for the reduction of physical load, through several ways [8]:

- Modification of layout from the point of view of ergonomics;
- Reduction of using the weight of machines, tools, and jigs which cause and increase physical load;
- Weight reduction of transferred burden - maximum or full time shift maximum weight;
- Provision of suitable physical factors of working environment;
- Change of working organization - using job rotation method;
- Continuous control of health state of workers which are exposed to physical load, and

- Regular control of health state of workers.

Limit values of physical load for manual handling with burdens are legislatively anchored in the government regulation of SR No. 281/2006 Coll [9]. The next table presents a selection of guideline limit values of weights which is necessary to observe at work with burdens, considering the age and sex of workers.

Table 1 Selection of guideline limit values of weights at work with burdens [9].

Indicative weight values of transferred and both hands lifted burdens					
Age	**Conditions**	**Maximum weight of burden (kg)**		**Maximum full-time shift weight (kg)**	
		Men	**Women**	**Men**	**Women**
18-29	Favourable	50	15	10,000	6,500
	Unfavourable	40	10	8,000	5,500
30-39	Favourable	45	15	7,500	6,500
	Unfavourable	40	10	7,200	5,500
40-49	Favourable	40	15	6,500	6,000
	Unfavourable	35	10	6,000	5,500
50-60	Favourable	35	10	5,500	5,000
	Unfavourable	30	5	5,000	4,000

Indicative weight values for lifting and transferring of burdens for woman in basic and standing position			
Maximum weight of transferred and manual lifted burdens (kg)	**Length of vertical track of burden**	**Maximum number of lifts per minutes**	**Maximum distance (m)**
15	floor - wrist	6	8
	wrist - shoulder	5	
10	floor - wrist	8	10 - 15
	wrist - shoulder	7	
	floor - shoulder	5	
5	floor - wrist	10	15 - 20
	floor - shoulder	8	
	floor - over shoulder	6	
	wrist - shoulder	10	
	wrist - over shoulder	8	
	arm - over shoulder	5	

Particular values (mentioned in following table) represent the suitability of worker activity which is performed, depending on age and sex of workers, and the weight of burden in relation to the frequency of operations and length of duration. Observance of these limit values ensures the work for employees will not cause excessive physical load. The worker will be not exposed to health risks associated with the formation of excessive physical load.

Key Indicator Method as tool for analysis of working environment and physical load

The use of the Key Indicator Method (KIM) is one of the possible methods for determination of working conditions and physical load finding. The basic key indicators are posture, working conditions, and burdens. This method is integrated into special methods and is applicable for manual handling tasks.

The basic requirement is realisation of analysis during one working day. It is necessary to determine average values of variable parameters as burden load or posture [10].

The first KIM was the KIM for lifting, holding, and carrying (KIM-LHC). The blueprint was developed in 1996, tested, and validated until 1999. In 2000, the revised version was published. The first purpose was to develop a method in order to support risk assessment for manual handling of loads at the national level [11].

The method solves the identification of working conditions and physical load in 3 basic steps:

- Score determination - evaluation of time;
- Score determination - evaluation of key indicator, and
- Total evaluation.

The KIM was developed over decades (**Figure 1**). It was used for risk assessment at the screening level in the case of physical workloads. Potential users include occupational safety and health stakeholders and industrial engineers in companies, as well as ergonomists, occupational health physicians, employer and employee associations, and insurance companies or research facilities [12].

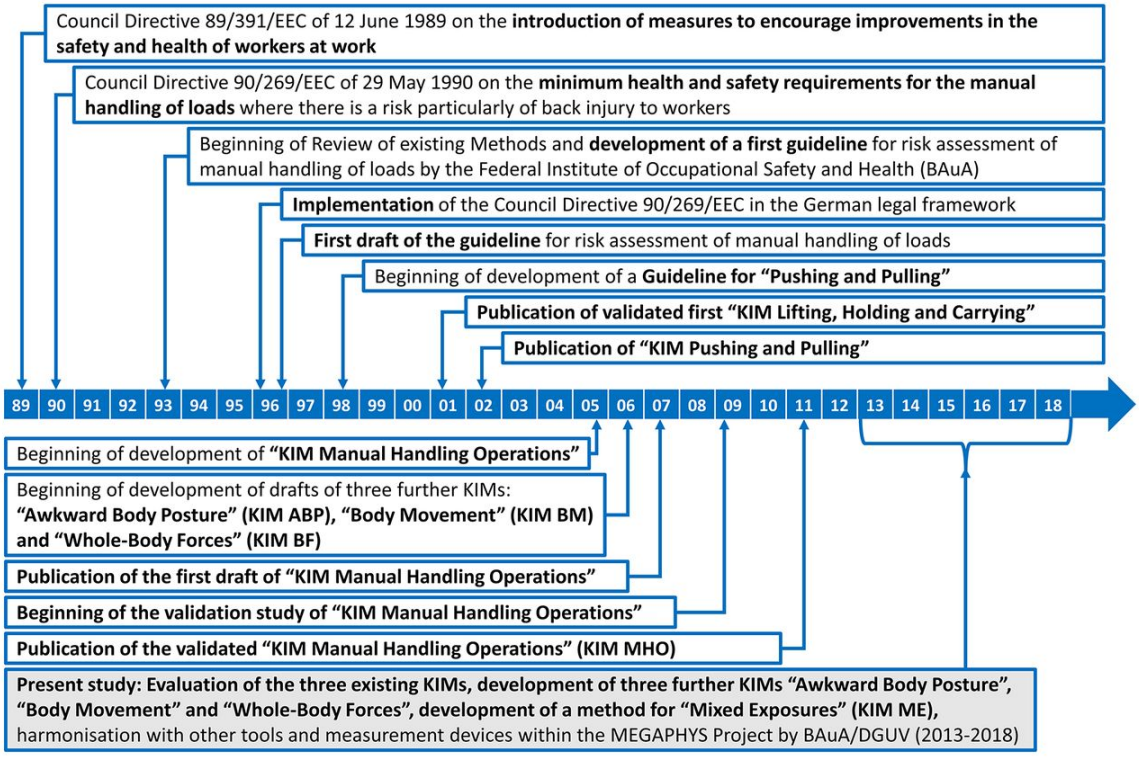


Figure 1 KIM development [12].

Score determination - evaluation of time

Scores are determined by tables for individual forms of manipulation with burdens (**Figure 2**). It individually considers manipulation with burdens over short distances with frequent stopping and manipulation over long distances.

- The basic determinant for manipulation over short distances is frequency and the basic determinant for manipulation over long distances is total distance (average velocity of walking is 4 km/h).

• For manual handling tasks which are characterized by the regular repetition of short lifting, lowering or moving is the determinant for the time rating score for the number of operations.

• For manual handling tasks which are characterized by burden holding total holding time (total time = number of lifting operations × duration of one lifting operation) is determined.

Lifting or displacement operations (< 5 s)		**Holding** (> 5 s)		**Carrying** (> 5 m)	
Number on working day	**Time rating points**	*Total duration on working day*	**Time rating points**	*Overall length on working day*	**Time rating points**
< 10	1	< 5 min	1	< 300 m	1
10 to < 40	2	5 to 15 min	2	300 m to < 1km	2
40 to < 200	4	15 min to < 1 hr	4	1 km to < 4 km	4
200 to < 500	6	1 hrs to < 2 hrs	6	4 to < 8 km	6
500 to < 1000	8	2 hrs to < 4 hrs	8	8 to < 16 km	8
≥ 1000	10	≥ 4 hrs	10	≥ 16 km	10

Figure 2 Score determination - evaluation of time [10].

Score determination - evaluation of key indicator

Evaluation of key indicators consists of three individual parts - evaluation of burden weight, worker posture in the performance of working activity, and evaluation of working conditions.

Score determination - burden weight

Scores are determined by tables individually for women and for men (**Figure 3**).

•In manipulation with different burdens, the average value is determined value when the individual burden does not exceed 40 kg for men and 25 kg for women.

•Active load is allowed for lifting, holding, transferring, and placing. The weight of active load is presented by the force of weight which the worker must balance. Burden does not correspond with object weight. If the object is inclined, the effect of weight is only 50 %. Pushing and pulling of burdens are considered individually.

Effective load for men	**Load rating point**	**Effective load for women**	**Load rating point**
< 10 kg	1	< 5 kg	1
10 to < 20 kg	2	5 to <10 kg	2
20 to < 30 kg	4	10 to <15 kg	4
30 to < 40 kg	7	15 to < 25 kg	7
≥ 40 kg	25	≥ 25 kg	25

Figure 3 Score determination - burden weight [10].

Score determination - posture

In this case, the basis for evaluation is in advance defined pictographs which are situated in a special table (**Figure 4**). They allow for typical postures during manipulation with burdens. If more postures are

defined, the average value is determined according to a score number during evaluation of working position, standing for a considered task of manual manipulation.

Typical posture, position of load[2)]	Posture, position of load	Posture rating point
	• Upper body upright, not twisted • When lifting, holding, carrying und lowering the load is close to body	1
	• Slightly bending forward or twisting the trunk • When lifting, holding, carrying und lowering load is near to medium to body	2
	• Low bending or far bending forward • Slightly bending forward with simultaneous twisting of trunk • Load far from the body or above shoulder height	4
	• Bending far forward with simultaneous twisting of trunk • Load far from body • Restricted stability of posture when standing • Crouching or kneeling	8

Figure 4 Score determination - posture, position of load [10].

Score determination - working conditions

It is necessary to use working conditions which are dominant over the course of time in score evaluation for working conditions. Occasional discomfort is disregarded, as this is irrelevant from the point of view of safety.

Working conditions	Working conditions rating point
Good ergonomic conditions, e.g. sufficient space, no physical obstacles within the workspace, even level and solid flooring, sufficient lighting, good gripping conditions	0
Space for movement restricted and unfavourable ergonomic conditions (e.g. 1: space for movement restricted by too low high or working area less than 1,5 m^2 or 2: posture stability impaired by uneven floor or soft ground)	1
Strongly restricted space of movement and/or instability of centre of gravity of load (e.g. transfer of patients)	2

Figure 5 Score determination - working conditions [10].

Total evaluation

Every task is evaluated by score evaluation of danger related to the activity (summary of key indicator score evaluation and its multiplication of scores during time evaluation). If this task is performed by women, the score evaluation is multiplied by coefficient 1.3, because women have two-thirds performance in comparison with men. The score is precisely determined by the Federal Institute for Occupational Safety and Health.

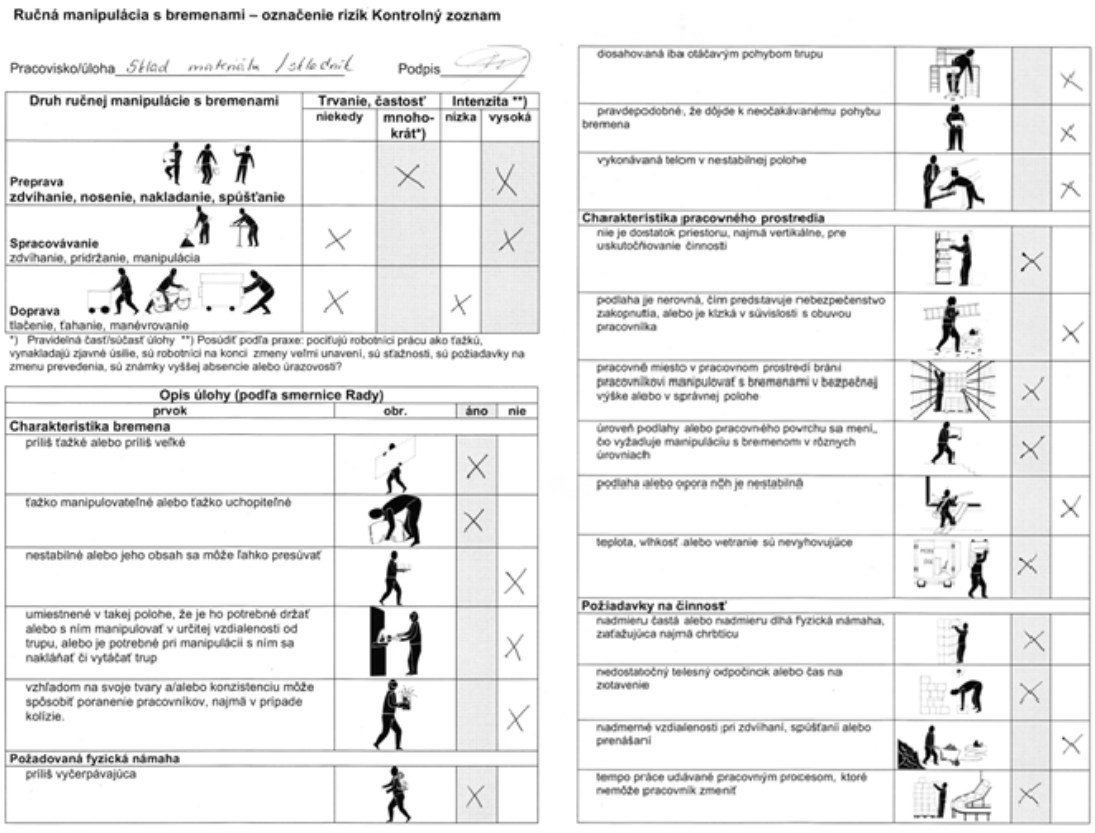
The basis of evaluation is the probability of health damage. This is constituted by mechanisms of biomechanical and physiological activities, which are combined with batching models. It is considered that the internal strain on the muscular and skeletal system depends on a critical rate of expended physical forces.

Example of KIM application for determination of inadequate physical load in practice

Evaluation by the KIM was applied at the warehouse of a selected construction company. Application was composed of the following steps:

Risk specification - 1st step

Particular risks were marked by a control list. This was completed by workers directly in the workplace and consisted of 5 parts - kind of manipulation, burden characteristic, physical labour, description of working environment, and claims to work activity. The completed control list is represented in the following figure.



Ručná manipulácia s bremenami – označenie rizík Kontrolný zoznam

Pracovisko/úloha Sklad materiálu / skladník Podpis

Druh ručnej manipulácie s bremenami	Trvanie, častosť		Intenzita **)	
	niekedy	mnoho-krát*)	nízka	vysoká
Preprava zdvíhanie, nosenie, nakladanie, spúšťanie		X		X
Spracovávanie zdvíhanie, pridržanie, manipulácia	X			X
Doprava tlačenie, ťahanie, manévrovanie	X		X	

*) Pravidelná časť/súčasť úlohy **) Posúdiť podľa praxe: pociťujú robotníci prácu ako ťažkú, vynakladajú zjavné úsilie, sú robotníci na konci zmeny veľmi unavení, sú sťažnosti, sú požiadavky na zmenu prevedenia, sú známky vyššej absencie alebo úrazovosti?

Opis úlohy (podľa smernice Rady)			
prvok	obr.	áno	nie
Charakteristika bremena			
príliš ťažké alebo príliš veľké		X	
ťažko manipulovateľné alebo ťažko uchopiteľné		X	
nestabilné alebo jeho obsah sa môže ľahko presúvať			X
umiestnené v takej polohe, že je ho potrebné držať alebo s ním manipulovať v určitej vzdialenosti od trupu, alebo je potrebné pri manipulácii s ním sa nakláňať či vytáčať trup			X
vzhľadom na svoje tvary a/alebo konzistenciu môže spôsobiť poranenie pracovníkov, najmä v prípade kolízie.			X
Požadovaná fyzická námaha			
príliš vyčerpávajúca		X	
dosahovaná iba otáčavým pohybom trupu			X
pravdepodobné, že dôjde k neočakávanému pohybu bremena			X
vykonávaná telom v nestabilnej polohe			X
Charakteristika pracovného prostredia			
nie je dostatok priestoru, najmä vertikálne, pre uskutočňovanie činnosti		X	
podlaha je nerovná, čím predstavuje nebezpečenstvo zakopnutia, alebo je kĺzka v súvislosti s obuvou pracovníka			X
pracovné miesto v pracovnom prostredí bráni pracovníkovi manipulovať s bremenami v bezpečnej výške alebo v správnej polohe		X	
úroveň podlahy alebo pracovného povrchu sa mení, čo vyžaduje manipuláciu s bremenom v rôznych úrovniach		X	
podlaha alebo opora nôh je nestabilná			X
teplota, vlhkosť alebo vetranie sú nevyhovujúce		X	
Požiadavky na činnosť			
nadmieru častá alebo nadmieru dlhá fyzická námaha, zaťažujúca najmä chrbticu		X	
nedostatočný telesný odpočinok alebo čas na zotavenie		X	
nadmerné vzdialenosti pri zdvíhaní, spúšťaní alebo prenášaní			X
tempo práce udávané pracovným procesom, ktoré nemôže pracovník zmeniť		X	

Figure 6 Risk marking - control list (current state).

Partial workplace evaluation and load by KIM - 2nd step

Evaluation was realised between 8:00 am and 4:00 pm. It was selected and realised one segment - removing the burden from rack, its transfer, and placing it in a new place (**Figure 4**) from all of the working postures which related to the transfer of the burden from point A to point B. The worker (53 years old) carries the burden total 180 - times, weighing 35 kg, on a tract with length 10 m during the working time (evaluation according to **Figure 3** - effective load for men). The worker walks 500 m during the 8 h shift (evaluation according to **Figure 1** - carrying). Partial evaluations of parameters are presented in the following figure.

Typical posture, position of load[2]	Posture, position of load	Posture rating point
	+ Upper body upright, not twisted + When lifting, holding, carrying und lowering the load is close to body	1
	+ Slightly bending forward or twisting the trunk + When lifting, holding, carrying und lowering load is near to medium to body	2
	+ Low bending or far bending forward + Slightly bending forward with simultaneous twisting of trunk + Load far from the body or above shoulder height	4
	+ Bending far forward with simultaneous twisting of trunk + Load far from body + Restricted stability of posture when standing + Crouching or kneeling	8

Effective load[1] for men	Load rating point
< 10 kg	1
10 to < 20 kg	2
20 to < 30 kg	4
30 to < 40 kg	7
≥ 40 kg	25

Carrying (> 5 m)	
Overall length on working day	Time rating points
< 300 m	1
300 m to < 1 km	2
1 km to < 4 km	4
4 to < 8 km	6
8 to < 16 km	8
≥ 16 km	10
Examples: - furniture removal, - delivering scaffolding parts to a building site	

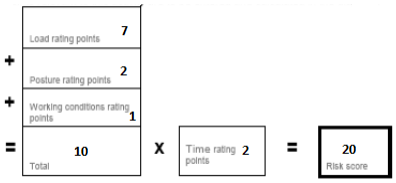
Working conditions	Working conditions rating point
Good ergonomic conditions, e.g. sufficient space, no physical obstacles within the workspace, even level and solid flooring, sufficient lighting, good gripping conditions	0
Space for movement restricted and unfavourable ergonomic conditions (e.g. 1: space for movement restricted by too low high or working area less than 1,5 m^2 or 2: posture stability impaired by uneven floor or soft ground)	1
Strongly restricted space of movement and/or instability of centre of gravity of load (e.g. transfer of patients)	2

Figure 7 Partial evaluation of load.

Total evaluation of workplace and load by KIM - 3rd step

The total evaluation of workplace and load was realised after partial evaluation and follow - up obtaining of required values. Obtained values were inserted into the evaluation chart, which is presented in **Figure 8**, which informs the reader of the score of danger. This score was assigned range later.

(a)



(b)

Risk range ***)	Risk score	Description
1	<10	Low load situation, health risk from physical overload is unlikely to appear.
2	10 to <25	Moderate load situation, physical overload is possible for less resilient persons. For this group redesign of workplace is helpful.
3	25 to <50	Increased load situation, physical overload also possible for normally resilient persons. Redesign of workplace should be reviewed.
4	≥50	High load situation, physical overload is likely to appear. Workplace redesign is necessary.

) *The boundaries between the risk ranges are fluid because of the individual working techniques and performance conditions. The classification may therefore only be regarded as an* ***orientation aid*. Basically it must be assumed that as the number of risk scores rises, so the risk of overloading the muscular-skeletal system increases.*

Figure 8 Evaluation chart (a) and evaluation table (b).

On the basis of the above-mentioned, it is necessary to suggest changes, because the workplace shows heightened danger. The subject of suggested rationalisation change is the reduction of excessive load during carrying of burdens.

Sketchup Pro - digital software for creation of optimization solving

Software Sketchup Pro is a digital tool which is used for the creation of 3D models. For model creation, the basis is a 2D sketch of geometric figures which obtain a 3D form after they are pushed out or pressured in space. Then, the formed 3D models are adjusted in space, ensuring advanced required arrangement [13].

An optimization model for reduction of danger in the workplace was created. The demolition of the second floor of the warehouse and the subsequent installation of racks was necessary from this suggestion. This optimization solving is based on the results of the control list with marking of increased physical load during the carrying of burdens and overcoming stairs at the same time.

The first optimization model was constructed without the second floor of the warehouse. It has 2 steel racks with dimensions of 20,000×1,200×4,500 mm^3 in it. A feeder was added (**Figure 8**) which eliminates loads of worker in this optimization model. This feeder is composed with steel construction and stands on a steel floor. The construction of the feeder is attached with 2 steel arms for the sake of stability. The arms are linked with the upper part of the feeder to shelfs. On the top and bottom part of the feeder, a toothed belt is attached, which is used for movement (x-axis) of the feeder central part. The central part is composed from 3 vertical steel columns. Two columns form the central construction, which is moved by cogs in a horizontal direction along the upper and lower toothed belts. The third central column part has a toothed belt, being a traversed arm of the feeder. The third column is the z-axis. The arm (moving shifter fork) is attached perpendicularly to the column. The arm presents the y-axis and has a weight and toothed belt. The moving part of the feeder moves lengthways along the rack.

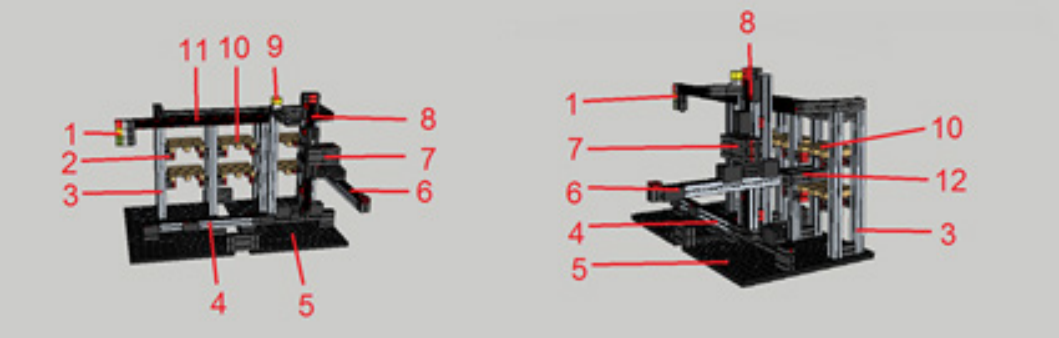


Figure 9 Scheme of feeder.

Legend to Figure 9:

1 - indicator light
2 - holder of pallet
3 - rack construction
4 - lower belt (moving: x-axis)
5 - floor
6 - arm of feeder (y-axis)
7 - weight
8 - vertical belt (z-axis)
9 - warning light
10 - pallet
11- upper belt (moving: x-axis)
12 - forks for pallet

An advantage of the feeder is seen when the customer needs only a few pieces of material. The feeder carries a pallet with material near to the floor in order for the worker to not have to bend down or reach out for material.

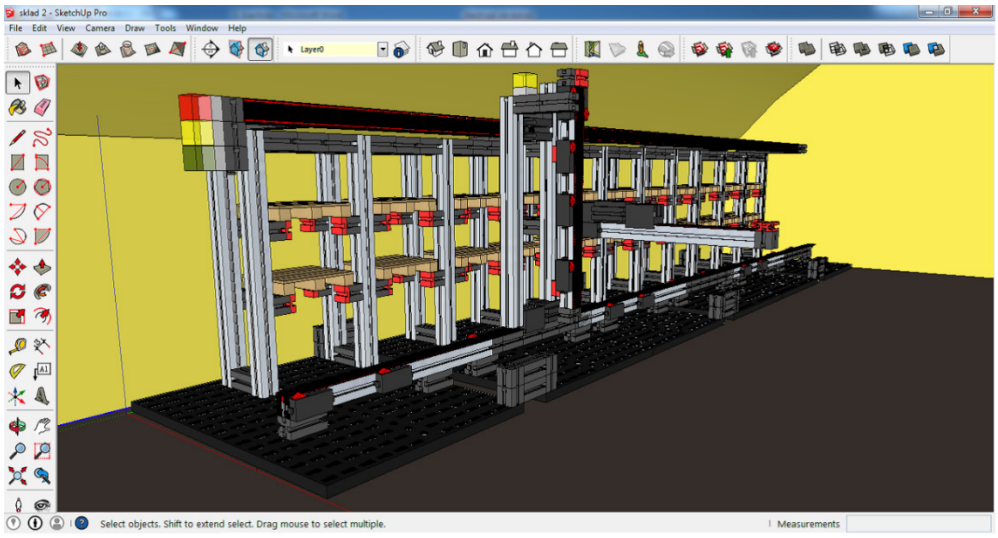


Figure 10 Optimization model with feeder.

The second optimization model was constructed without the second floor of the warehouse. It has 2 steel racks with dimensions of 20,000×1,200×4,500 mm^3 in them. It was added with a fork-lift truck. The advantage of this suggestion is the moving of the truck in space. This means that it is possible to store

material in other places promptly. This suggestion saves time which is needed for loading up material on trucks. Material must be loaded up on pallets. This suggestion is unsuitable in the case of a customer placing an order for only a few pieces of goods.

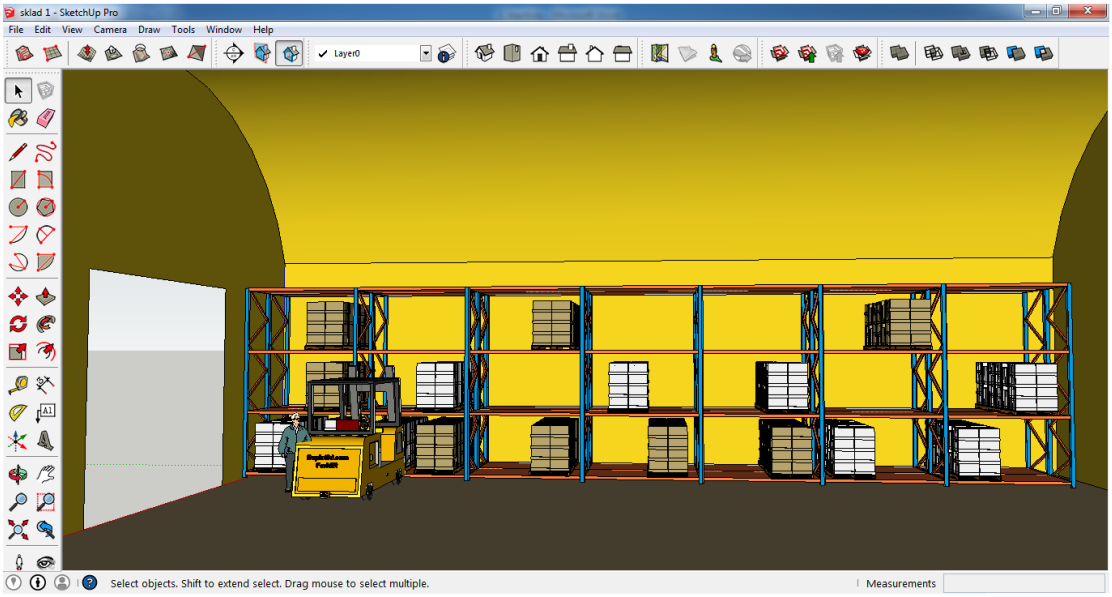


Figure 11 Optimization model with fork-lift truck.

The next table presents an overview of rationalization solving evaluation. It shows that, after the application of rationalization arrangements decreased, the total evaluation, which was realised by the KIM, and the range level of danger was decreased, too.

Table 2 Overview of evaluation of physical work rationalization.

Key Indicator Method		Before rationalization	After rationalization
Partial evaluation	A: Time evaluation	2	1
	B: Carrying [m]	2	1
	C: Active load [kg]	7	7
	D: Posture	2	2
	E: Working conditions	1	0
Total evaluation (evaluation chart - **Figure 7**)		20	9
Range level of danger		2	1

Conclusions

Working load presents a factor which causes harm for humans in work and, depending on extent of effect, it disturbs working well-being or results in the origins of illnesses or injuries. Every field of industry tries to prevent the occurrence of these problems [14,15]. Physical load presents only one part of a complex analysis of working activities.

The above-mentioned model does not remove the total physical load of workers, but it can reduce this load to acceptable values [16]. It decreased total physical load of workers from the value of 20 to 9 after the realisation of repeated analysis. This presents a reduction of 55 %. The obtained results are obtained only for environment with a low appearance of danger. In this case, the danger represents burdens and physical loads and it is improbable according to the evaluation table. It reduced the track of burden carrying and improved total working conditions by realising rationalization arrangements.

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