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Interdisciplinary Research Project: Principles of Work Scheduling

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The research project is established to develop a "connection" between the daily working hours and the resulting performance of the workers. The research concentrates on the sector of carcass work, especially with the focus on bricklayer´s work. The aim of the research project is to set up personnel body parameters by monitoring the working process and the corresponding load and exposure of the workers combined with the achieved output during the investigation. Out of these investigations a connection between the workload and the fatigue should be determinated for the first time by a mix of three interdisciplinary investigation methods, which were until now only independently used. In this paper the first step to develop the aim of the research project is presented. A task analyses to develop the percentage of a single activity was done. Additionally, the mean workload of bricklayer´s workers was determinated by comparing different physiological criteria with limits suggested by different researchers. It became clear that the overall workload for bricklayer´s workers is under each of these limits but there are large deviations between the rates of the workload for each individual.

Keywords: REFA workflow analyses, workload, exposure of bricklayers, work scheduling.

1 The Research Project

1.1 *Motive*

During the execution of construction work certain differences between the planned working process and the actual performed work on the construction site can be recognized. The reasons for these differences can be varied. On one hand it can be necessary for the contractor to change the time schedule, on the other hand the differences may be due to disturbances of the value performance and it becomes necessary to arrange accelerating measures. The evaluation of the performance loss due to extended working time – as instrument to the definition of measures – is essential in order to make a decision. This process happens in allusion to the method introduced by Vygen / Schubert / Lang (2008) whereby the time course of performance, the so-called performance curve of Winter (1966) functions as foundation for the calculation. Another source of performance evaluation was demonstrated by Lehmann (1962). Both of the mentioned performance curves show a decline of labor performance during a certain time of a work shift and it is possible to calculate these changes of the work performance factor, hence the changes of the overall performance can be evaluated to costs. These two elaborations on the topic “working capacity“ were established in the 1960s. Lehman (1962) described the physiological changes and effects as a consequence of physical work and derived a performance curve by this approach. Winter (1966), whose publishment based on the research of Burkhardt (1964), demonstrated a decrease in performance as a consequence of extended working shifts in an observation of “digger and scraper performances”. Schlagbauer (2006) showed however that the boundary conditions of the working curves have changed. These changes concern the improved equipment technology, the specialization on certain fields of responsibilities as well as the development of new construction equipment and developments in safety engineering. These highlights that massive changes evolved in the working field of construction workers and therefore the prediction of the decrease of performance can only be illustrated conditionally with the curves of Burkhardt/Winter or Lehmann.

1.2 *Objective*

In order to provide possibilities to the construction industry an adapted performance curve has to be developed applying a multi-dimensional observation to better display the real actual working situation.

The main objective of this research project is the creation of a performance curve for bricklayer´s work that depends on the work completed. This curve will be the result of the combination of different, performance influencing components, to prove a decrease in performance as a consequence of extended working hours. The first step in the research project was to determinate the main tasks performed by a construction worker and the identification of the corresponding workload for a specific sector. These two topics will be presented in this paper after the introduction to the general research concept to specify the workload for bricklayer´s work. For the determination of the workload the results of a cycle ergometer exercise test were combined with the analysis of the heart rate measurements on the construction site. This method follows the ideas of Lehmann (1962), Bink (1962), Brouha (1967), Astrand and Rodahl (1970) or Jørgensen (1985) who brought up the idea to compare parameters which were collected by observation of the work (e.g. mean heart rate (HR_{mean}), mean oxygen consumption ($V´O_{2,mean}$) or mean energy expenditure EE_{mean}) with personnel parameters (e.g. maximum heart rate, (HR_{max}), maximum oxygen uptake ($V´O_{2,max}$) or the individual physical working capacity (EE_{ind})).

2 Research structure

The study bases on an empiric investigation on different chosen construction sites and additional sports scientific research in the lab of the Human Performance Research Graz (HPR^{Graz}). In the course of the data collection on the construction sites the allocation of the activities, the heart rate development during the working day, the influence parameters of the climate and additional influence parameters for the classification of the construction site situation have been investigated.

2.1 Construction site investigation

2.1.1 *Workflow analysis*

In the course of this research project construction workers were observed during carcass work, where attention was especially paid to brick layers. The workflow analysis was performed using the system of REFA (1984) and were executed with multi-moment-recordings. Thereby the particular activity of the observed construction worker was documented in a five minute interval.

2.1.2 *Recording climatic influences*

Simultaneously to the activity recordings, air temperature, wind velocity and air humidity were recorded in order to determine additional physical exertion. The data collections were executed on similar construction sites at different times of the year in order to evaluate seasonal influences, which will be introduced in this research project.

2.1.3 *Heart rate measures*

During the observation period the heart rate was continuously measured and stored in a fifteen second interval (Polar Electro S810, Finland). The results of these measurements were allocated to the respective activity from the multi-moment-record. The different physiological "starting conditions" of the investigated subjects made it necessary to calibrate the physical performance potential. These sport medical investigations were realized by the research partner HPR^{Graz} with the aid of a standard cycle ergometer exercise.

2.1.4 *Collection of additional parameters*

Additional information concerning the boundary conditions of the respective construction site was collected. This information contains the time schedule, construction site logistics, construction methods, working atmosphere and experience of the construction workers. By using this additional information the comparability of the analyses from the different construction sites was improved.

2.1.5 *Performance progress*

Along with the above mentioned factors the performance progress of the observed construction workers was recorded in a 30 minute interval with sketches and photographs. In the continuous data analysis, which is not the object of this paper, a correlation between performance improvement and the physical strain of a construction worker takes place. The aim is to develop an activity dependent performance curve.

2.2 Data evaluation

2.2.1 Evaluation of the activity analysis

In order to evaluate the activity analysis the recorded examinations were collected in a database. In allusion to the classification of activities according to REFA a distinct classification matrix was developed. In this adapted matrix system the recorded data was split in two classification levels in different categories. The categories in the first level of tasks are "Occupation", "Interruption" and "Not identifiable". The category "Occupation" is furthermore subdivided in "Main activities", "Ancillary activities" and "Additional activities". Interruptions are broken down into the 2nd level categories "Due to workflow", "Due to dysfunction", "Due to recreation" and "Due to personal needs". After allocating the activities to different categories in the first and second level the percentage of the categories was calculated for each workday and the whole investigation period as well as for each construction worker individually and generally for all construction workers.

2.2.2 Evaluation of the heart rate measurement on the construction site

In order to evaluate the recorded heart rate the data was imported via software and prepared for further usage by eliminating errors caused by disturbing signals or measurement errors which occurred in the data collection.
For the further investigation of the workload the mean heart rate was used to calculate the mean oxygen consumption and the mean energy expenditure of the workday using standard formulae (Astrand and Rodahl 1970).

2.2.3 Evaluation of the lab research

The results of the cycle ergometer exercises, which were executed in a lab, provided individual body-characteristics of each observed construction worker (age, body height, weight, as well as the development of the heart rate, the lactate concentration, the oxygen consumption and the carbon dioxide production in relation to power output).

3 Results of the data analysis

3.1 Subjects

In the course of this research project 13 construction workers were observed while performing bricklayer´s tasks, whereby 8 of them underwent sports medical investigations in the lab. Table 1 shows the physical characteristics of the investigated workers. For all construction workers in 95 observation days 6261 individually carried out activities were recorded.

Table 1. Physical characteristics of the construction workers

Worker	age (years)	Weight (kg)	Stature (cm)
1	41	76.5	178.5
2	39	93.0	181.5
3	22	76.0	186.5
4	19	85.0	167.0
5	35	145.0	191.0
6	55	124.0	189.0
7	22	66.0	171.0
8	22	94.5	178.0
Mean	31.88	95.0	180.3
SD	11.92	25.0	7.9

3.2 Conditions of the investigated construction sites

During miscellaneous conversations with the construction workers, the foreman and the construction supervisor, it became clear that there was no acceleration needed in order to keep up to the time schedule during the observation period. Furthermore we found that the crews had already worked together on previous working sites in the same composition and that the working climate could be evaluated as “excellent”.

3.3 Results of the activity analysis

The evaluation showed the following result: on the first category level the construction site workers were at mean 75.43% occupied with the execution of activities and were for 24.57% of the time interrupted during this.
The distribution on the second category level is represented in the following table.

Table 2. Activity distribution
2nd Level Categories (N=6261)

Category	percentage
Main activities	38.34 %
Ancillary activities	34.45 %
Additional activities	2.63 %
Interruption due to workflow	1.60 %
Interruption due to dysfunction	0.93 %
Interruption due to recreation	16.49 %
Interruption due to personal needs	5.54 %

As shown in the table above, the investigated main and ancillary activities sum up to over 70% of the working day. When it comes to interruptions the conclusion can be drawn that interruptions due to recovery cause the major part of brakes with 16.49% of the working time. At a closer glance at this category it can be seen that these 16.49% are made up 12.86% by restricted brakes by the employer and 3.63% by individually chosen breaks of the workers additional to the 5.54 % interruptions due to personal needs.

3.4 Determination of the workload

For the determination of the workload first the evaluation of the heart rate measurements had to be done for every construction worker individually. The mean heart rates (HR_{mean}) of all observed days were calculated and the results were displayed in table 2. Beside this mean heart rate the mean oxygen consumption

($V'O_{2,mean}$) and the mean energy expenditure (EE_{mean}) of each construction worker during the observation were calculated by using the information of the cycle ergometer exercises data.

Table 3. Individual physiological characteristics of the construction workers

Worker	HR_{mean} (beats min^{-1})	$V'O_{2,mean}$ (l_{O2}/min)	EE_{mean} (kcal/min)
1	93.62	1.11	5.42
2	99.38	1.06	5.12
3	110.24	0.69	3.43
4	95.74	0.78	3.72
5	95.43	1.22	6.51
6	98.42	*	*
7	96.53	0.76	3.64
8	101.20	0.81	3.92
Mean(S.D.)	99.1(4.7)	0.92(0.19)	4.52(1.09)

*invalid data for worker 6

The next step in order to evaluate the physical workload was to compare the measured heart rates and the according oxygen consumption and the energy expenditure with limits set up by different researches in the last century.

The first of these limits was brought up by Muller (1953) and Lehmann (1962) who suggested that the maximum energy expenditure (EE_{abs}) during heavy work should be about 4 kcal/min. Due to additional investigation Astrand and Rodahl (1970) increased the value to a rate of 5 kcal/min for performing work continually without overly taxing the worker.

Additional to this absolute value Bink (1962) set up a limit for the physical workload in relation to the working time (t) and aerobic capacity (a) which is related to the age of the construction worker (Astrand 1960) by Eq(1).

$$EE_{ind} = \frac{\log 5700 - \log t}{3.1} * a \quad \text{..............(1)}$$

In difference from the limits mentioned above Brouha (1967) set up a heart rate limit by suggesting the an average heart rate of 110 beats min^{-1} should not be exceeded by industrial workers for eight hours working time. Similarly the World Health Organization assigned the heart rate limit at a rate of 110 beats min^{-1} for eight hours working time.

The third parameter to describe the physical work load is the oxygen consumption ($V'O_2$) compared to the maximum oxygen uptake ($V'O_{2,max}$). Based on an eight hour work shift the estimated ratio of $V'O_2$ and max$V'O_2$ according to different authors (Astrand and Rodahl 1970, Bink 1962) should be between 0.22 and 0.50 for an eight hour work shift. Saha et al. (1979) and Jørgensen (1985) also set up the limit with an estimated percentage of 33% of his/her $V'O_{2,max}$ for an eight hours working shift. In order to verify the investigated workload for bricklayer´s work the mean physiological characteristics illustrated in table 3 were compared with the limits mentioned above and displayed in the following table.

Table 4. Workload parameters for the construction workers

Parameter	Limit rate	Investigated rate Mean (S.D.)	% of Limit
HR	110	98.82(4.87)	89.8 %
$V'O_2$	33%	0.92(.019)/3.76(0.32)	74.2 %
EE_{abs}	5	4.54(1.07)	90.7 %
$EE_{ind,8h}$	5.81(1.38)	4.54(1.07)	78.1 %

Referring to the results in table 4 it can be suggested that the physical workload caused by bricklayer´s work under defined boundary conditions described in 3.2 will cause loss of productivity in case of prolonged work shifts.

As mentioned before there are differences in the individual constitution of each worker noticeable. To show the effect of the individual constitution two selected parameters were evaluated for each worker individually and ranked by the percentage.

Table 5. HR of the construction workers

Worker	HR_{mean} (beats min^{-1})	% of HR_{limit}	rank
1	93.62	78.7%	3
2	99.38	64.1 %	1
3	110.24	88.9 %	7
4	95.74	76.6 %	2
5	95.43	81.6 %	5
6	98.42	79.4 %	4
7	96.52	90.2 %	8
8	101.20	88.8 %	6
Mean(S.D.)	98.82(4.87)	89.8% (4.4%)	

Table 6. Energy expenditure of the construction workers

Worker	EE_{mean} (kcal/min)	% of $EE_{ind,8h}$	rank
1	5.42	125.4 %	7
2	5.12	96.1 %	6
3	3.43	65.7 %	3
4	3.72	61.2 %	2
5	6.51	74.7 %	4
7	3.64	80.4 %	5
8	3.92	60.3 %	1
Mean(S.D.)	4.54(1.07)	80.6 %(21.7%)	

A comparison of the rank for the same construction worker in the tables 5 and 6 shows that the use of an individual parameter limits causes a big discrepancy. For example worker 1 was ranked third at the HR limit but was ranked last at the EE limit by exceeding this limit considerably.

4 Summary

The illustration of the activity analysis shows that the observed construction workers were occupied with the carrying out of activities for 75% of the time, whereby approximately half of the time main activities were carried out, thus activities which conduce to the production of a sellable achievement. Similarly it is noticeable, that the part of recreational brakes dominates the part of the interrupted times. Taking into account the 12.86% which make up the part of the mandatory brakes of the employer, it shows that the brakes, which were not planned ahead, make up a part of 11.71%. In order to increase the development of productivity in the future even more, it is important to not only take construction site logistics into consideration but also the pressure due to the activities which have to be carried out. Looking at the examined mean workload it is noticeable that none of the limits were exceeded. By taking a closer look at the individual workload of each construction worker it became recognizable that the physical workload determinated by an absolute limit indicated big discrepancies when compared to the workload determinated by an individual limit and the individual energy expenditure limit was exceeded by one worker.

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