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MULTISKILLING IN CONSTRUCTION – A STRATEGY FOR STABLE EMPLOYMENT

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Abstract. After years of prosperity the construction industry is facing the current recession. This severely affects both construction companies and the workforce employed by them. The lack of skilled labour has always influenced construction outcomes, but, in the current economic environment, the problem is becoming more acute. The growth of unemployment among construction workers will cause additional social problems and does not alleviate the shortage of skilled craftsmen. A simulation model reflecting the performance of a construction firm is introduced. It enables the evaluation of different management strategies with consideration of the contradictory interests of owners, contractors and craftsmen in order to analyse the compromise and choose an appropriate solution for all parties.

Keywords: labour management strategies, multiskilling, workforce, simulation modelling.

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1. Problem recognition

Construction is a labour intensive as well as a craft-based activity and the behaviour of people has an enormous influence upon the organisation and performance of construction firms. Sustainable development of the construction industry has to focus not only on sustainable building technologies and construction materials but also on respectful and considerate labour management strategies. It is important to acknowledge that the workforce is an irreplaceable resource with erratic behaviour.

Our previous research (Lill 2004) and the literature review reveal a number of factors which have combined to induce a construction skills shortfall. These include:

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- the introduction of new technologies which have redefined the skills required (Agapiou *et al.* 1995; SLIM report 2002; Wells and Wall 2003);
- the growth in self-employment and the use of labour-only subcontractors which have reduced the commitment and investment in training within the industry (Alinaitwe 2008; Chini *et al.* 1999; Druker and Croucher 2000; Haksever *et al.* 2002; Janssen 2000). Self-employed craftsmen, in turn, appear unable to effectively manage their own qualification improvement issues and there is a direct correlation between the fall of trainee numbers and the numbers of self-employed (Crowley *et al.* 1997; Mackenzie *et al.* 2000; Syben 1998);
- the poor image of the industry which unfavourably affects its popularity as a career choice (Dainty *et al.* 2004; SLIMreport 2002; Tarnoki 2002). The image is low even among construction industry workers themselves to the extent that the majority of construction crafts workers (of various ages and experience) would never recommend their trade to their children (Liska 2002);
- the high mobility of construction workers as a result of the unattractive image, unsafe working conditions, the lack of respect and inadequate opportunities for training. Site safety and the quality of works are always the last to be considered as the conflict of interests in "earning" and "speed" arises (Ahmed *et al.* 2000; Fung *et al.* 2008; Idoro 2008; Navon and Kolton 2006; Tam *et al.* 2001);
- dissatisfaction with the way in which labour is organised, especially the unstable workload which has been cited as the principal reason for release by relieved workers (Cahuc and Postal-Vinay 2002; Haas *et al.* 2001; Kazaz *et al.* 2008; Smithers and Walker 2000);
- a set of problems related to issues of women in construction which deserve special attention from researchers (Charlesworth and Baird 2007; Dainty *et al.* 2000; Elvitigalage *et al.* 2008);
- globalisation has added an often negative ethnic characterisation of labour forces and therefore consideration of cultural differences within multi-lingual construction teams is increasingly important (Belić 2002; Bust *et al.* 2008; Jaselskis *et al.* 2008; Wilson 2003);
- the migration of the workforce to countries offering better wages (for example, the drain of the workforce from Eastern European countries since joining the European Union (EU).

The combination of these factors has led to a labour market reliant upon a casual workforce, incorporating high levels of self-employment, low levels of training investment and, hence, low quality skills (Briscoe *et al.* 2000; Dainty *et al.* 2004; Kashiwagi and Massner 2002).

The way in which construction work is planned, scheduled, and controlled has a direct bearing on workers' motivation and general satisfaction. Unfortunately, only a relatively small number of studies deal with construction craft workers as compared to construction materials and technologies. A comprehensive research has been conducted in Latvia, but this addresses workforce in general and is not construction-oriented (Dubra and Gulbe 2008). Considering the situation described above, we cannot underestimate the need for research regarding the construction workforce and this area of investigation is largely under-explored (Murray *et al.* 2002). Having been engaged in researching construction labour management strategies in Estonia for over twenty years now, it is interesting to note different phases of development:

- during the Soviet era, the main problems were a lack of workforce and low quality of work, but it was common that companies maintained their own workforce;
- later, immediately after independence and the reintroduction of capitalism in post-socialist countries, the principal driver was "maximum profit whatever it takes" and companies preferred not to have any responsibility for their own workforce and hired them mainly on a project basis. It was a time when craftsmen had to learn to survive by taking responsibility for themselves;
- then, during the post EU accession construction boom the situation changed and there was a severe shortage of construction workers as a result of previous short-sighted policy and better opportunities offered in the older EU member states. At that time every person who could hold a hammer was hired;
- now, when orders' portfolios are shrivelling, it might seem that the roles are reversed and that employers have a wide selection of skilled labour. Unfortunately, it is not as simple as it looks, because unemployment causes social problems and highly qualified craftsmen who have endured the previous phases can make their selections between companies too.

Thus the problem of labour management remains regardless of the economic environment. Improvement of management strategy itself is not an abstraction and, if the analysis of the current situation and best practice from other countries may be considered an appropriate foundation for research, then, in order to discern improvement, we need a quantitative evaluation of changes caused by different management strategies. Management is always a question of interests, moreover, the often contradictory interests of different parties. We could define at least three parties involved in construction:

- the owner who is interested in high quality buildings as quickly and as cheap as possible;
- the contractor as a service provider, concerned with a stable orders' portfolio, high profit and low costs;
- the craftsman, interested in a stable workload, satisfactory and safe working conditions and a fair salary.

This research is focused on finding a compromise between these parties. A construction firm management system model is presented; it enables the simulation of different management strategies and by quantitative estimations demonstrates that the welfare of craftsmen is in the best interests of both the owner and the contractor. Improvement of the organisation not only requires less capital investment than modernising technical equipment but it also alleviates the human resource problem of satisfaction with work. It is important to develop a sustainable attitude towards construction labour among decision-makers. The adoption of a management strategy should be based on an economic calculation rather than intuitional reasoning. This implies that we need an evaluation tool for estimating the outcomes of different management strategies consisting of sets of controversial goals. Mathematical methods of economic theory provide mostly qualitative answers: whether revenue will rise or fall if we change variables, but also quantitative answers for particular decisions. For our present purposes, we seek a quantitative evaluation of each management strategy rather than a single, specific managerial decision.

Simulation modelling enables the consideration of various different construction situations caused by different strategies without interfering in the real production process. This paper introduces the simulation model employed and describes its representation of the production and economic activities of construction firms together with all the conflicting restrictions they involve.

2. The impact of self-employment on the specialisation and training of craftsmen

2.1. Principles of specialisation

The profession of a construction craftsman has not been highly regarded for many years and this has a negative impact on the quality of construction works. The general reason for the low regard lies in unsatisfactory working conditions and management strategies. Many researches have tried to bring attention to these problems (Alinaitwe *et al.* 2008; Baiden *et al.* 2006; Belić 2002; Chan and Kaka 2003; Chini *et al.* 1999; Cotton *et al.* 2005; Dainty *et al.* 2004; Kazaz and Ulubeyli 2007; Kawaguchi 2003; Liska 2002; Mickaitytė *et al.* 2008; Mitkus and Trinkūnienė 2008; Nowak 2005; Odeh and Battaineh 2002; Paslawski 2008; SLIMreport 2002; Šarka *et al.* 2008; Šiškina *et al.* 2009; Turskis 2008; Yang and Chang 2005).

The ways construction work is planned, scheduled, and controlled directly bear on workers' motivation and general satisfaction. The unattractive image, unsafe working conditions, lack of respect and inadequate opportunities for training lead to the high mobility of construction workers and an irregular workload is reflected in fluctuating personnel numbers. From 10 to 22% of relieved workers mention unsatisfactory labour organisation, especially the unstable workload, as the reason of their release (Haas *et al.* 2001). Any increase in the volatility in the numbers of employed personnel will in turn reduce the likelihood of realising the construction programme.

Skill levels continue to decline while owners squeeze contractors for lower costs and faster schedules through the low-bid delivery process. In response, contractors reduce training and use less skilled craftsmen to be competitive (Kashiwagi and Massner 2002). Considering the safety issues involved in being in the construction field, it is no wonder that many craftsmen are opting to pursue other careers.

The coordination of the work of every employee in terms of time and space is a daily issue in any construction firm. Consequently, the creation of rational forms of cooperation and spatial distribution of workers is one of the most important issues of labour division in building enterprises. At a macro level it is possible to derive two opposing labour division strategies: single-skilling, where workers master one specific craft trade and multiskilling, where a craftsman is able to perform several trades. Both strategies have their strengths and weaknesses.

Single-skilled Craftsmen:

- From a positive perspective, single-skilled craftsmen can achieve high productivity and can raise their skill levels more easily as the same operations are frequently repeated. Therefore, the higher the level of specialisation, the higher the quality of work and the higher the productivity that can be achieved. The fact that there are normally several specialised teams on the building site at the same time requires precise coordination of their work in terms of time and space.
- However, it should be mentioned that narrow specialisation can be effective only if all workers are provided with work, otherwise efficiency falls because "for single-skilled workers, the work should be broken into small pieces, each piece or task involving a single skill" and this makes the scheduling process very complicated or even impossible for smaller companies (Haas *et al.* 2001). The division of the workers between a large number of building sites leads to deviations from the rational, technological order of works, fluctuation of workload and, consequently, labour productivity can fall dramatically.
- The efficiency of specialisation is primarily guaranteed by having the necessary quantity of work. Consequently, a stable and uninterrupted workload is possible in sufficiently large firms with a high number of buildings under construction.

Multiskilled Craftsmen:

- The research studies reveal that the benefits of multiskilling are labour cost savings and fewer workers needed; it also enables an increase in average employment duration and of earning potential for multiskilled construction workers. Research in Germany and the Netherlands showed that a broadly skilled and adaptable labour force accords well with higher levels of technical complexity in construction processes (Clarke and Wall 2000). The effectiveness of multiskilling has been expounded in several research reports on labour resources and has also been observed from practical experience (Gomar *et al.* 2002; Haas *et al.* 2001; Piper and Liska 2000; Slomp and Molleman 2002; Tam *et al.* 2001; Thomas and Horman 2002; Vidaković and Marić 2002). Multiskilling makes workers more competitive as they stay longer on a project; they can be utilized more flexibly including unforeseen maintenance activities and since multiskilled workers and crews have a broader variety of skills. When a multiskilled workforce is utilized properly, it should generate savings from lower turnover rates, higher productivity, and fewer accidents (Burleson *et al.* 1998).
- However, we have to be aware of possible consequences of multiskilling including the drop in average efficiency by about 15% (Hegazy *et al.* 2000; Vidaković and Marić 2002) and note that the endless mastering of additional skills cannot be reasonable and might lead to negative results (Clarke and Wall 2000).

2.2. Training issues for construction craftsmen

The last decades show a decrease in the amount of work directly accomplished by main contractors and a parallel tendency of passing an increasing proportion of the work over to subcontractors. Craft workers are hired for a specific job and laid off at its completion, indicating a lack of concern for the individual and a need for individual improvement. In this situation only a main contractor fulfils a project management function. There are two major reasons which cause the above-mentioned changes. Firstly, a main contractor trying to complete the majority of construction works with its own labour has to face unproductive expenses connected with an unstable workload and an irregular orders portfolio. Dismissal of workers is an option in order to reduce unproductive expenses. The second reason is connected with the owner. In a laissez-faire construction market, the owner's revenue is dependent on the duration of the construction and this is why owners continuously pressure contractors to shorten the length of the construction period, which in turn exacerbates the problem of an unstable workload.

The main contractors have responded to the unstable workload problem by decreasing the amount of their own labour if not abandoning it completely. Virtually all labour is now hired only when immediately required and laid off as soon as workloads fall. This brings about a general undermining of collective wages, social protection, and industrial relations in favour of work contracts or task works, casual employment and agency labour or, at the professional level, domestic work and freelance employment (Druker and Croucher 2000; Janssen 2000).

However, eliminating one problem results in a new one arising: the growth in labour-only subcontracting and self-employment has led to a decline in training, and this is illustrated by the direct correlation between the fall in trainee numbers and increasing self-employment. Eventually, the skills of workers will not develop as it is very rare that a formal training is provided by labour-only subcontractors or the self-employed themselves because of insufficient facilities, funds or will for training these groups (Crowley *et al.* 1997; Syben 1998). Where the vocational training system ignores the real needs of the construction market, this unquestionably works against the well-being of the industry. It would be hard to find anyone who would claim that skill training or qualification improvement is useless, but, when it comes to finding time or money for them, the attitude is not so favourable. Investing in the workforce should be supported by the knowledge that it really pays off and yields measurable profit.

In this research, we try to find a compromise between the interests of the different parties in order to motivate them to improve the competence management of construction craftsmen which eventually will contribute to the welfare of the whole construction industry.

2.3. Influence of the construction programme

It is inevitable and intrinsic to building technology that it is almost impossible to provide an even workload for all workers of different trades on the building site during the whole construction period (Chini *et al.* 1999; Druker and Croucher 2000; Hegazy *et al.* 2000; Kapliński 2008; Kashiwagi and Massner 2002; Kazaz *et al.* 2008; Tam 2001; Thomas and Horman 2002; Vidaković and Marić 2002). To explore the depth of the problem, the extent of the differences between main contractors depending on the type of buildings constructed by them was investigated. It was found that main contractors always face labour management problems no matter what type of building was constructed (Sutt 1985; Sutt and Lill 2002b). The efficiency of a construction firm working in a multiproject environment depends on the construction duration of every single project and the intensity of its resource usage. Contractors have to vary the amount of labour applied to an activity depending on the amount of work available (Thomas and Horman 2002). The aspirations of reducing the length of the construction period and providing an even workload to all craftsmen of different trades are contradictory as the improvement in the first factor leads to a worsening of the second and vice versa (Sutt and Lill 1996; Sutt and Lill 2002a). One of the contractors' arguments as to why they avoid a directly employed workforce and prefer to work on the basis of subcontracting is that their orders portfolios and construction programmes are unstable. The study of typical labour resource histograms can indicate which combinations of skills are most preferable and in compliance with schedule demands (Haas *et al.* 2001).

We have conducted a detailed survey where construction projects in 25 firms were monitored during 5 years in order to learn whether the construction programme is stable enough to provide craftsmen with permanent work. High values of standard deviations led us to the conclusion that the distribution of building types in construction firms is of a random character and that contractors are forced to accept all offers due to heavy competition. Distribution of craftsmen by trades in the same construction firms and during the same period was also chaotic.

The next step was to estimate the severity of the situation and find an answer to the question: How significant is the impact of a construction programme on the workforce composition by trades? The results obtained from the research on the structure of works in different building types were encouraging: no matter how changeable a construction programme is, the requirements in professional composition are rather stable and consequently an unstable construction programme should not be used as an excuse for rejecting construction craftsmen. However, the need for different trades was constant only on average over the planning period whereas, at different time intervals, overloads and slack times were unavoidable when single-skilled craftsmen were hired.

This leads to the conclusion that a certain amount of craftsmen can be successfully used as the firm's own workforce if they are multiskilled workers, though the number of combined trades and their reasonable combinations remains open. These answers could be obtained by conducting different construction situations with simulation methods.

3. Simulation modelling of the construction firm management system

3.1. Outline description of the simulation system

Simulation techniques enable the comparison of the efficiency of several alternative solutions without intervention in the real construction process. The major problem of simulation modelling concerns the adequacy of the modelled objects. This will be a key factor when wider conclusions on real systems are being drawn. The initial simulation model for evaluating different management strategies in construction was created by Prof. J. Sutt where the possibility of creating sensitive models and computer software for such kind of investigations was proved (Sutt 1985; Sutt and Lill 1996). His main focus at that time was the influence of construction duration. The simulation system was further developed for the evaluation of labour management strategies and especially the efficiency of multiskilling (Lill 2004; Sutt and Lill 1996; Sutt and Lill 2000). On the basis of these investigations, a system of models was created and the resulting simulation model has been continuously modified with relevant changes and reconfigured to enable the evaluation of the economic efficiency of investments in the construction workforce. A comprehensive description of the research methodology may be found in the previously cited research reports and, therefore, only an overview is presented here.

The performance of a construction firm is modelled as a network of schedules (a multi-project system), detailed up to the level of resource usage (labour, building materials, machinery, finances). Economic assessments are derived from profit information (resources and projects) in the form of relative assessments of the most profitable simulation version of the firm. The management strategies are modelled as resource restrictions (amount, treatment), project restrictions (duration, deadlines, and succession) and necessary cost additions for different management strategies.

The entire model is based on the concept of a firm that simultaneously works on a variety of construction projects. The management subsystem of a construction firm involves three different management outlines as presented in Fig. 1.

The upper part of this scheme reflects the management subsystems of Buildings under Construction (B_1, B_2, B_3, ..., B_n) with the project manager at the head of every building site and respective working staff. Restrictions coming from building technology are taken into account there. The goal of every single subsystem is to maximise its profit. The Resource Management subsystems (labour, plant, materials, and finances) are listed at the bottom. The

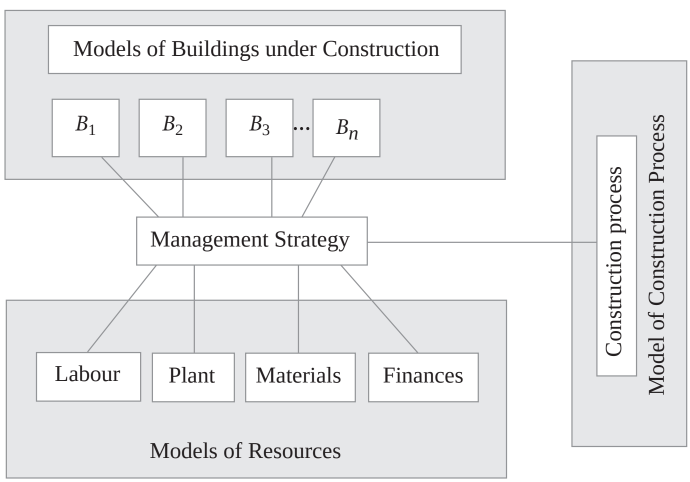

Fig. 1. Model of construction firm management system

goal of each one of these is to supply the construction site with resources of proper quality and of possibly minimal cost.

The Management subsystem of the Construction Process is placed on the right. Its aim is to provide continuous profit generation for the firm: marketing, time-scheduling in a multi-project environment, financial book-keeping and its supporting functions like quantity surveying, preparing new technologies, etc. It is possible to schedule a continuous production process from the aspect of IT by using information about buildings under construction in the form of network schedules which reflect the technological links and quantities of works on the one hand and information about resources available to the firm (amount, quality, restrictions if any, productivity) on the other.

Different construction situations are created by using the Generator of Construction situations and by changing the parameters in the Model of Buildings and in the Model of Resources.

The central problem in this research is to find out if and how the contractor's profit is influenced by different ways of combining trades among workers. In this approach, the variables are the number of combined trades assigned to a worker and different ways of combining trades to create multiskilled workers while the general quantity of labour remains constant. The workers' specialisation by trades corresponds to the Models of Buildings presented in a form of network schedules where works are detailed up to every single-skilled trade. This requires the aggregation of the topology of the network regarding the trades used. In the simulation process, the topological aggregation automatically changes according to varying schedules of compliance between the activities and trades.

Simulation was based not only on increasing the number of combined trades but also on several different ways of combining trades, which cause respective changes in network topology. Every activity in the network is described by a number of parameters: identification codes for the works and trades; technologically justified minimum and maximum number of workers for each task; labour consumption; cost of capital investments and works, costs of materials, machinery, workers' wages, etc.

3.2. Model of economic assessment

The efficiency of combining trades is investigated on the basis of detailed building situations, modelled as a multi-project time schedule for the construction firm and considering the respective changes in the Model of Buildings and the Model of Resources. The efficiency of the performance of a construction firm depends on two aspects of the building process modelled in the form of a time schedule:

- *Duration*: the difference between the planned construction duration of each building and the one obtained on simulation leading either to fines (if the simulated period exceeds the planned one) or bonuses (if the simulated period is shorter);
- *Intensity*: the parameters characterising the use of limited labour resources (idle time or overloads, the frequency of transferring workers from one building site to another, etc.).

The efficiency assessments are calculated separately for the contractor (E') and for the owner (E'). The use of multiskilled workers is characterised by the number of combined trades – n. For every value of n, three different ways of combining trades were modelled.

For the contractor, using multiskilled workers influences the construction cost price through changes in seven of its components. The first three components are related to direct labour costs and reflect the uniformity of the workload. The changes of the construction cost price are caused either by idle time (E_1'), overloading (E_2') or changes in costs connected with transferring workers from one building site to another (E_3'). The remaining four components of the cost price reflect the changes in the length of the construction period caused by the changes in the use of labour. These include the changes in the costs of using building machinery (E_4'), expenses on temporary buildings (E_5'), costs of keeping the street section and building site in good order (E_6') and the costs of interest on loans (E_7').

The supplementary costs resulting from idle periods in work can be expressed on the basis of the time-schedule by the following equation:

$$E_1^{'} = \alpha \cdot \beta \sum_{j=1}^{J} \sum_{t=1}^{T^P} \Delta_1 \left| n_{jt}^P - n_{jt}^0 \right|, \tag{1}$$

where α – the workers' average wages, in monetary terms per shift; β – the ratio, considering the part of wages, paid during disruptions. The value of β varies in firms, but if the layoffs are caused due to the contractor, the workers must be compensated and these charges can be interpreted as "wasted money" or unproductive costs; n_{jt}^P, n_{jt}^0 – planned (modelled in the schedule) and available (pre-set in the restrictions) number of workers of j – trade (j = 1, 2, ..., J) on the working day t(t = 1, 2, ... T^P), where T^P is the number of working-days in the planning (modelled) period and

$$\Delta_1 = \begin{cases} 1, if\,(n_{jt}^P - n_{jt}^0) < 0, \\ 0, if\,(n_{jt}^P - n_{jt}^P) \geq 0. \end{cases} \tag{2}$$

In practice we do not often meet such expenses because firms simply prolong the committed construction deadlines, avoiding thus the idle period. Another option is sending unloaded workers on the buildings without strict limits on terms. Thus we can admit that E_1' is competent if the deadline is pre-set for all the buildings under construction. On the other hand, the assessment $\frac{E_1^{'}}{\alpha \cdot \beta}$ could be used as an argument for the inclusion of the number of buffer buildings (buildings with no duration limits) in the construction programme.

During the simulation of construction process, the duration depends on the number of workers and their average output per capita. In situations, when all the workers are already involved but there are still some tasks without time reserves, the following possible solutions can be offered:

– to exceed the mean norms of output (overtime work);
– to take some additional workers,
– to use workers in the second- or night-shifts.

All these mentioned options bring along supplementary costs that can be expressed as follows:

$$E_2^{'} = \gamma \cdot \alpha \sum_{j=1}^{J} \sum_{t=1}^{T^P} \Delta_2 (n_{jt}^P - n_{jt}^0), \quad (3)$$

where γ – the ratio, considering the part of wages paid for overtime. The value of γ varies in firms as there may also be several solutions. Nevertheless, if overtime work is caused due to contractor's fault the craftsmen should be compensated for their effort or if some extra-workers are hired for evening or night shifts, it brings along additional costs;

$$\Delta_2 = \begin{cases} 1, if\,(n_{jt}^P - n_{jt}^0) > 0, \\ 0, if\,(n_{jt}^P - n_{jt}^0 \le 0. \end{cases} \quad (4)$$

As there are several buildings under construction simultaneously and all the workers should be provided with work, it is unavoidable to transfer workers from one building to another which involves the following costs:

$$E_3^{'} = \omega \cdot \alpha \sum_{k=1}^{K} \sum_{j=1}^{J} (n_{jk}^1 + \sum_{r-1 \ge \upsilon \ge 1} \left| n_{jk}^{\upsilon} - n_{jk}^{\upsilon+1} \right| + n_{jk}^r - \frac{2N_{jk}}{T_{jk}}), \quad (5)$$

where ω – expert assessment of the lost working time while transferring workers from one building site to another; $n_{jk}^1, n_{jk}^{\upsilon}, n_{jk}^r$ – number of workers of j – trade respectively on the first, on υ and on r (the last) time interval on the building $k(k = 1, 2, ..., K)$; T_{jk} – the duration of work for workers of j – trade on the building k, in shifts; N_{jk} – the amount of man-shifts for workers of j — trade on the building k, in man-shifts.

The costs of building materials are constant for one-shift working regimen and do not depend on either the intensity of workforce or the construction duration and therefore, neither from the number of combined trades. More uniform workload, achieved as a result of multiskilling, obviously carries along more full and stable workload of the building machinery as well, which in turn leads to changes in the construction duration and concentration of resources on the building site. The changes in non-recurring costs of the building machinery operation can be performed on the basis of time-schedule parameters by the following equation:

$$E_4^{'} = \frac{\sum_{k=1}^{K} (2T_k^N - T_k^F)}{\sum_{k=1}^{K} 2T_k^N} \sum_{k=1}^{K} \sum_{s=1}^{S} \mu_s E_k^s, if\,(T_k^F \ge T_k^{\min}), \quad (6)$$

where $T_k^N, T_k^F, T_k^{\min}$ are respectively the normative (pre-set), real (modelled) and technological minimum durations of works on the building k; μ_s – the share of non-recurring costs in the total cost of the building machinery for the s-type of work $s(s = 1, 2, ..., S)$; E_k^s – estimated total cost of the operation of building machinery for the work s at the building k.

The rest of the direct construction costs do not depend directly on the combination of trades. But the impact of multiskilling could be expressed through respective changes in the construction duration. We presume that the estimated expenses on the temporary buildings correspond to the concentration of resources which guarantees the normative (pre-set) construction duration. In that case, the supplementary costs of the temporary buildings caused by the shortening of construction duration could be displayed as follows:

$$E_5^{'} = \begin{cases} \eta \sum_{k=1}^{K} \left(\frac{T_k^N - T_k^F}{T_k^N} \right) \cdot B_k \frac{C_k^P}{C_k}, if\,(T_k^F < T_k^N), \\ 0, if\,(T_k^F \geq T_k^N), \end{cases} \tag{7}$$

where η – ratio of temporary buildings cost rate to the concentration rate of resources; B_k – estimated total cost of temporary buildings on the building *k*; C_k, C_k^P – estimated total cost of works on the building *k*, in total and in the planning period respectively.

The costs of keeping the street section are also proportionate to the construction duration. Thus, the impact of combining trades on these expenses could be measured through respective changes in construction duration:

$$E_6^{'} = \sigma \sum_{k=1}^{K} \left(\frac{T_k^F - T_k^{\min}}{T_k^{\min}} \cdot C_k^P \right), \tag{8}$$

where σ – is the normative cost foreseen for holding the street section in the total cost of works.

The supplementary costs spent on loan interests in case of prolonging the construction duration T_k can be displayed as follows:

$$E_7^{'} = (\varepsilon_1 + \varepsilon_2) \sum_{k^*=1}^{K^*} C_{k^*}^P, \tag{9}$$

where ε_1 – fine for delay of the construction duration; ε_2 – loan interest for using the bank credit, $C_{k^*}^P$ – cost of uncompleted construction on the prolonged building k^*.

The owner's interests can be expressed through the owner's potential revenue, which is influenced by the change in construction duration caused by multiskilling. This research reveals that the minimum construction duration is achieved by raising the number of multiskilled trades to maximum. Thus, the changes in the owner's revenue are estimated against the minimum construction duration.

In that case, the owner' supplementary revenue on the industrial buildings could be displayed by the following equation:

$$E_1^{''} = E_a \sum_{k_{ind}=1}^{K_{ind}} \frac{Q_{k_{ind}}}{(1+E_{NN})^{T_{k_{ind}}^F}} \cdot (T_{k_{ind}}^F - T_{k_{ind}}^{\min}), \tag{10}$$

where E_a – the normative efficiency of capital investments; E_{NN} – the normative net present value; $Q_{k_{ind}}$ – capital investments in the industrial building $k_{ind}\,(k_{ind} = 1, 2, ..., K_{ind})$ or the average profit norm in the firm; $T_{k_{ind}}^F, T_{k_{ind}}^{\min}$ – real (modelled) and technological minimum construction duration on the industrial building k_{ind}.

The respective efficiency changes of non-industrial buildings are evaluated through calculating the expenses entailed by freezing up the investments, or as non-received profit:

$$E_2^{''} = E_a \sum_{k_{non}=1}^{K_{non}} \frac{Q_{k_{non}}}{(1+E_{NN})^{L_{k_{non}}^F}} \cdot (L_{k_{non}}^F - L_{k_{non}}^{\min}), \tag{11}$$

where $Q_{k_{non}}$ – the capital investments in the non-industrial building $k_{non}\,(k_{non} = 1, 2, \ldots, K_{non})$, or the average rate of non-received bank interest; $L_{k_{non}}^F, L_{k_{non}}^{\min}$ – the real (modelled) and technological minimum durations of holding the investments in the non-industrial building k_{non} while

$$L_{k_{non}} = \frac{\sum_{r=1}^{T_{k_{non}}} Q_{k_{non}}^r (T_{k_{non}} - r - 0.5)}{Q_{k_{non}}}, \tag{12}$$

where r – the construction periods when the capital investments are made in the building k_{non} (the order number of a day); $Q_{k_{non}}^r$ – the capital investments at the day r in the building k_{non}.

The owner's potential revenue depends also on the change of cost price as the result of using multiskilled craftsmen:

$$E' = \sum_{i=1}^{7} E'_i. \tag{13}$$

The summary efficiency function on the owner's level could be suggested as:

$$E^{''} = E^{'} + E_1^{''} + E_2^{''}. \tag{14}$$

The number of combined trades and their combinations are the guided parameters in the simulation experiment and efficiency assessments are calculated for every value of these parameters.

4. Results of the simulation

The purpose of this simulation experiment is to evaluate various labour usage strategies in order to find management solutions for chosen priorities. Quantitative assessments of cost and revenue functions are based on the simulation of a construction process and economic activities of an average construction firm erecting buildings of different structural and functional groups.

The results of experiments showed that the efficiency depends on the number of trades while the impact of different combinations of multiskilling was insignificant. Thus, in the further analysis of the experiment, we are going to represent the changes of economic assessments caused by the multiplying of trades only, whereas the details of combinations (which trades are combined) will be ignored.

The aim of the chosen strategy of construction management is to ensure that the modelled works are accomplished with maximum intensity so that every building could be finished within the estimated construction duration (T^N) which is the first priority over workload stability. As there is a shortage of available resources, changes of intensity (such as idle periods and working overtime) are allowed. The available number of workers by trades established in the restrictions can be ignored in cases where there is no time left for the particular work. As the length of the construction period and also the buildings under construction are very different, we have to use a relative duration as a measuring unit. The benchmark for a relative length of construction period could be the construction duration – T^N. If we name the construction duration of a particular project obtained during the simulation as T^N, the relative duration can be expressed as a ratio T^F/T^N. In Figure 2 the change of relative construction duration depending on the number of combined trades is presented.

Using multiskilled workers makes it possible to shorten the relative construction duration by approximately 30%. However, it is obvious from the dynamics of the function T^F/T^N that the maximum shortening (20%) is achieved by multiplying the number of combined trades up to 4, while assigning only 2 or more than 4 trades changes the duration assessment by only about 5%.

The number of combined trades affects the construction cost price through the respective changes of its components, reflecting the uniformity of workload $(E_1^{'}, E_2^{'}, E_3^{'})$ and the economic assessments determined through the changes of construction duration $(E_4^{'}, E_5^{'}, E_6^{'}, E_7^{1})$.

In Fig. 3 the summary curves of these components are displayed. The curve $E^{'} = \sum_{i=1}^{7} E_i$ reflects the changes of the construction cost price for the contractor with no buffer buildings in the plan, which means that $E_1^{'}$ has also been taken into account and craftsmen are paid for idle periods. The curve $E_{B^{'}}^{'} = \sum_{i=2}^{7} E_i$ represents the changes of the cost price of those construction firms which have included the buffer buildings into their programme, which means that $E_1^{'}$ is not taken into account.

The analysis of the curve $E^{'}$ dynamics shows that the maximum changes of cost price occur when the number of combined trades rises up to four whereas the cost price falls respectively by 3% (with no buffer buildings in the plan) and by 1.5% (with them). The further assigning of trades decreases the cost price approximately 2%. This fact should be taken into consideration when an incentive system for multiskilling is established. Similar results have

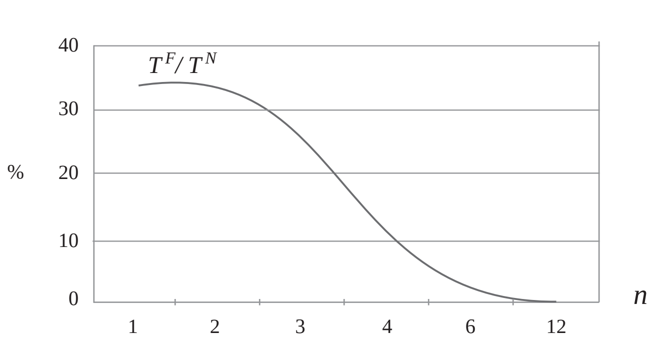

Fig. 2. Dependence of construction duration on the number of combined trades

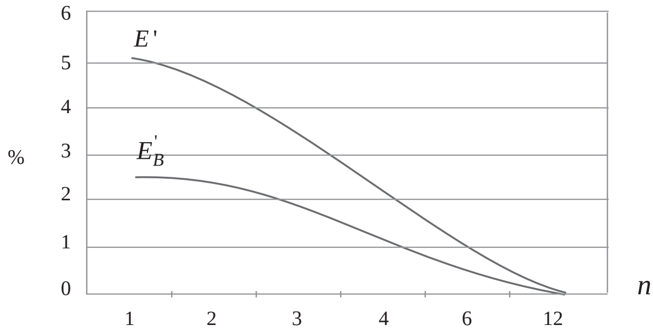

Fig. 3. Dependence of cost price on the number of combined trades

been obtained by (Gomar *et al.* 2002) who concluded "that benefits of multiskilling become marginal after acquiring competency in two or three crafts".

With the purpose of evaluating the efficiency from the owner's perspective E'' behaviour was analysed. The owner's interests are expressed through his potential revenue which is influenced by the change of construction duration resulting from multiskilling. E''_1 represents the changes of potential revenue from industrial buildings and E''_2 – from holding the investments in non-industrial buildings. From the owner's viewpoint it would be most profitable to have workers with a wide skills' profile because this allows the minimum construction duration. But the dynamics of the E'' graph lead to the conclusion that the potential revenue benefits are essentially achieved in raising the number of combined trades up to 4 (about 7%). The effect of further increasing the number of assigned trades is less significant.

Could there be a solution that satisfies all the parties – the contractor, the owner and the craftsmen? To find an answer we studied both the owner's revenue function E'' and the curve of contractor's cost price E' linking them to each other in Fig. 4.

The results of the simulation experiment show that the costs of a construction firm increase by 5% compared to the most favourable solution. It is clear that the contractor's costs

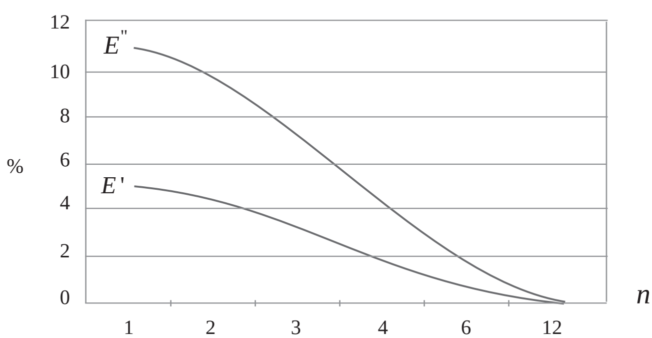

Fig. 4. Summary functions of contractor's costs (E') and owner's revenue (E'')

connected with multiskilling should be reflected in the construction cost price. If the respective growth of the owner's summary revenue E'' is higher than E', there are both means and interest. To escalate the contractor's interest in multiskilling it would be fair to suggest that the owner should give up a part of the remaining profit and use it to provide an incentive for the contractor. The most effective and reasonable solution would be to divide the profit 50:50.

The results of the simulation modelling proved that the interests of the contractor and the owner in multiskilling are obvious. Consequently, there is a need to find a way to make construction craftsmen interested in multiskilling as well. One way could be to cover the training and certification expenses for the craftsmen. But, considering the increasingly common practice where firms prefer not to tie themselves to a permanent workforce and the perception that certified craftsmen might choose to leave to competitors, it would be difficult to convince contractors to invest in training. Another option is that craftsmen themselves start investing in their knowledge but they have to be sure that their effort will be appreciated in monetary terms and that they will be paid remarkably better after learning additional skills.

We can suggest a particular proportion of profit for a multiskilling bonus. The size of the bonus fund could be 50% of the potential reduction of cost price, attained as a result of multiskilling (see Fig. 4). Let us name it conditionally a multiskilling fund *MF* and it could be calculated as follows:

$$MF = \Phi \cdot C, \tag{15}$$

where Φ is a ratio considering the efficiency of multiskilling and C is the estimated total cost of works in the planning period. The money from this fund can be divided between the craftsmen through the ratio depending on the number of combined trades λ as follows: craftsmen combining two trades – λ_2 = 20%; craftsmen combining three trades – λ_3 = 30%; craftsmen combining more than three trades – λ_4 = 50%. The suggested distribution corresponds to the efficiency curve of multiskilling where the most significant part of the effect was attained by raising the number of combined trades up to 4, while combining more trades was economically not reasonable (see Figures 2, 3 and 4). The calculation of supplementary payments – q_2, q_3, q_4 for multiskilling depending on the number of combined trades is suggested below:

$$q_2 = \frac{\lambda_2 \cdot MF}{\lambda_2 \cdot N_2 + \lambda_3 \cdot N_3 + \lambda_4 \cdot N_4}, \tag{16}$$

$$q_3 = \frac{\lambda_3 \cdot MF}{\lambda_2 \cdot N_2 + \lambda_3 \cdot N_3 + \lambda_4 \cdot N_4}, \tag{17}$$

$$q_4 = \frac{\lambda_4 \cdot MF}{\lambda_2 \cdot N_2 + \lambda_3 \cdot N_3 + \lambda_4 \cdot N_4}, \tag{18}$$

where N_i is amount of workers combining i trades.

5. Conclusions

The statistical analysis of the internal structure of works for buildings under construction leads to the conclusion that, no matter how changeable a construction programme is, the requirements for the composition of the workforce in terms of trades is rather stable if the contractor could use multiskilled workers. However, for single-skilled craftsmen, overloads and slack periods would be unavoidable. It would be reasonable to keep a multiskilled team on a permanent basis and motivate craftsmen in their qualification improvement. This should improve the quality of work and also raise the workers' loyalty towards their employer.

A model was created in order to simulate the efficiency of multiskilling. The subsequent simulation enables the evaluation of quantitative economic assessments of the effects of combining trades. We learned from the simulation experiment that multiskilling decreases the construction cost price through improving workload characteristics and a consequential shortening of the construction duration. We can draw the following conclusions:

- Using multi-skilled workers makes it possible to shorten the relative construction duration by approximately 20% due to a more uniform and full workload for craftsmen.
- Combining four trades decreases the cost price around 3% and increases the potential owner's revenue by approximately 7%. The influence of combining more than four trades is relatively insignificant as is the effect of using different specific combinations of trades. The analysis of the efficiency assessments from the perspectives of a construction firm and an owner reveals that both of them have an interest in multiskilled craftsmen, indicating that it would be worthwhile to pay workers for the additional skills they have acquired.
- Including some buffer buildings into the construction programme improves the arrangement of labour resources. The required quantity of works on buffer buildings is about 16% from the total cost of the main buildings under construction. The more multi-skilled craftsmen are involved, the less buffer buildings are needed.

The simulation experiment proved that multiskilling should interest both the contractor and the owner. Consequently, there is a need to find a way to encourage craftsmen to acquire additional skills. A simple incentive scheme is suggested for motivating craftsmen: a construction firm should give 50% of the effect from multiskilling to an incentive fund. The money from this fund could be divided between the craftsmen depending on their number of combined trades and with regard to the efficiency curve for multiskilling. In this way the compensation for multiskilling will be high enough to motivate craftsmen to learn additional skills. Another option would be to use the same amount for training the craftsmen.

The simulation system is an original tool which has passed a probation period in different economic environments. It enables various economic investigations into the construction business to be carried out and it also provides a platform for students doing independent analysis. Construction-production functions are usable for optimization of investment and construction strategies. The simulation model developed can be used in construction firms as well as in a university context to aid the learning process in construction economics, construction planning and IT courses and for comparing different construction management strategies.

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GRETUTINĖS SPECIALYBĖS STATYBOJE − DARNAUS UŽIMTUMO STRATEGIJA

I. Lill

Santrauka

Po klestėjimo metų statybos pramonė susiduria su nūdienos recesija. Ji smarkiai veikia tiek statybos įmones, tiek jų darbo jėgą. Kvalifikuotų darbuotojų stoka visada darė poveikį statybos įmonių veiklos rezultatams, o dabartinėje ekonominėje situacijoje, problema vis labiau aštrėja. Augantis statybininkų nedarbas sukelia papildomų socialinių problemų, tačiau neišprendžia kvalifikuotos darbo jėgos stokos problemos. Sukurtas modelis, kuriuo galima imituoti įmonės veiklą. Juo galima vertinti įvairias valdymo strategijas įvertinant prieštaringus savininkų, rangovų ir darbininkų interesus ieškant kompromiso bei renkantis visoms šalims priimtiniausią variantą.

Reikšminiai žodžiai: darbo jėgos valdymo strategijos, gretutinių specialybių įgijimas, darbo jėga, modeliavimas.

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