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Time/cost optimization using hybrid evolutionary algorithm in construction project scheduling

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ABSTRACT

This paper deals with construction project scheduling. In the literature on the subject one can find such scheduling methods as: the Linear Scheduling Model (LSM), Line of Balance (LOB) charts and CMP/PERT network planning. The methods take into account several objective functions: the least cost, the least time, limited resources, work priorities, etc., both in the deterministic and probabilistic approach. The paper presents an analysis of the time/cost relationship, performed using time coupling method TCM III. A modified hybrid evolutionary algorithm (HEA) developed by Bożejko and Wodecki (A Hybrid Evolutionary Algorithm for Some Discrete Optimization Problems. IEEE Computer Society, 325–331, 2005) was used for optimization.

1. Introduction

Time Coupling Methods (TCM) naturally stem from the Work Breakdown Structures (WBS) adopted in the sector system. Time couplings are internal interdependencies between construction processes and sectors, which take into account resource and technical constraints. The scheduling of construction projects by TCM, based on a matrix model, consists in planning construction projects for the above constraints and employing queuing optimization (branch and bound, B&B).

Linear Scheduling Methods (LSM), corresponding to TCM but based on a different approach, were developed mainly in Canada and the USA. O'Brien [1] introduced the notion of the 'Line of Balance'. The subject was taken up by Carr and Meyer [2] and Halpin and Woodhead [3]. Peer [4], Selinger [5], Handa and Barcia [6], Chrzanowski and Johnston [7] developed the 'Construction Planning Technique', O'Brien [8] and Barrie and Paulson [9] – the 'Vertical Production Method', Birrell [10] – the 'Time–Location Matrix Model', Johnston [11], Stradal and Cacha [12] – the 'Time Space Scheduling Method', and Thabet and Beliveau [13] – 'Horizontal and Vertical Logic Scheduling for Multistorey Projects'. O'Brien [8], Arditi and Albulak [14] and Melin and Whiteaker [15] developed tools for cyclogram optimization. Recent research [16,17] deals with resource requisition optimization in construction project scheduling. Harris and Ioannou [18] work on regular cyclograms. Adeli and Karim [19] conducted research into modelling using artificial neural networks for the purposes of construction project cost optimization. A survey of the current state-of-the-art can be also found in Chassiakos and Sakellaropoulos [20] and Zhao and Liu [21]. This work is the continuation of author's research on constructing efficient algorithms to solve hard problems of management which can be applied in construction (Bożejko and Wodecki [22,23].

Time Coupling Methods (TCM) Afanasjew [24–30] Mrozowicz], Hejducki] and Hejducki and Rogalska , differ from the above scheduling methods in this that work execution technologies and resource requisition are preassumed, i.e. no worker downtime in method I, no downtimes in sectors in method II, minimum completion time and possible worker and sector downtimes in method III and minimum time and additional constraints in methods IV, V and VI. The calculations are based on matrix notation.

The schedule (cyclogram) parameter calculation assumptions of LSM and TCM are presented below. The key quantities in the cyclograms are the lead times of the particular processes in sectors and control points (CP). The following symbols (commonly used in the literature on the subject) are introduced (Fig. 1):

- LT (Least Time) the shortest time distance between a process underway and the next process (connected with distance between sectors);
- LD (Least Distance) the shortest (space) distance between the process underway and the next process;
- CPH (Controlling Path) a critical path of construction processes;
- CL (Controlling Link) a graphical link between consecutive processes;
- CP (Controlling Point) a point corresponding the commencement of the next process;
- *T* (Time) the duration of a process;
- TT (Total Time) lead time;
- m the number of processes;
- n the number of sectors.

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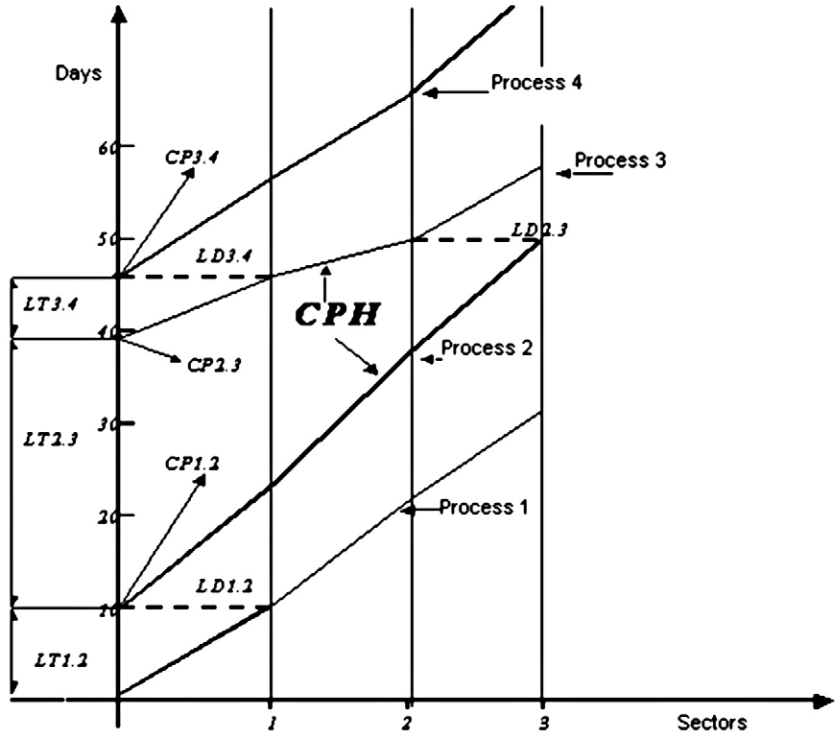

Fig. 1. Continuous processes, symbols.

The assumptions for calculating schedule parameters are as follows:

I Continuity of construction processes for each type (TCM I)

LT1.1…LT$n.m$ = 0

II Continuity of construction processes in a technological sequence (TCM II)

LD1.1…LD$n.m$ = 0

III A minimum critical path (TCM III, IV and V)

CPH = TTmin

In this paper an attempt is made to optimize the time/cost relation with regard to additional time buffer costs in TCM III with a critical path, corresponding to classical CPM/PERT. The hybrid evolutionary algorithm (HEA) developed by Bożejko and Wodecki [31] was used for this purpose.

2. Basic assumptions

TCM III is used when the priority is to ensure the minimum project lead time. This goal is pursued by adopting such priority internal interdependencies that both LD and LT in each case approach zero Fig. 2.

In TCM III work stoppages in individual sectors may occur and the continuity of the processes, and so the continuity of work of the contractors, may be not maintained. An ideal solution is a schedule in which both LT and LD are equal to zero. Using, for example, the B&B method one seeks such a sequence of carrying out work in the sectors which would ensure the best result, i.e. TT = TTmin. In TCM III all the internal interdependencies are considered to be priority interdependencies Fig. 3, i.e. there is no one kind of priority interdependencies as in TCM I and TCM II.

A lot of projects are carried out assuming a minimum lead time and fixed resources. Previously time minimization was applied only to some major projects but today at a wide access to resources and very high construction costs TCM III is increasingly often applied. Frequently TT = TTmin determines the choice of a method.

In TCM III most of the leading processes are conducted without any time reserves (i.e. nonstop) whereby the processes may be on the critical path. For the other works time intervals, i.e. periods of time between the earliest work commencement date and the latest work completion date, are determined. For this reason usually possibly the earliest work commencement dates, whereby the works are protected by time reserves, are adopted. This problem is also solved using the critical chain methodology (CCS/BM). One should note that it is possible to optimize the time/cost relationship: such a position of noncritical works can be found which will ensure the minimum objective function value. The objective function applies to cost optimization (minimization) at a minimum construction project duration with time buffers provided for noncritical works. In practice, rational planning consists in carrying out works and paying for them as late as possible (at the latest dates). Since it is possible to ensure time buffers for noncritical works, using, for example, CCS/BM, the question arises what the total increase in construction project costs will be for the latest work completion dates. The determination of the relationship between the total increase in construction project costs and the size of the time buffers is a highly computationally complex problem belonging to NP-difficult problems. Therefore applying exact methods, such as branch and bound (B&B) needs huge computations time, which is impossible in practice. Another approach can be based on using approximation methods, such as hybrid evolutionary algorithm (HEA) [31].

Fig. 4 shows the optimization computation methodology employing a genetic algorithm. The methodology is described in papers by Holland (1975) and Goldberg [32].

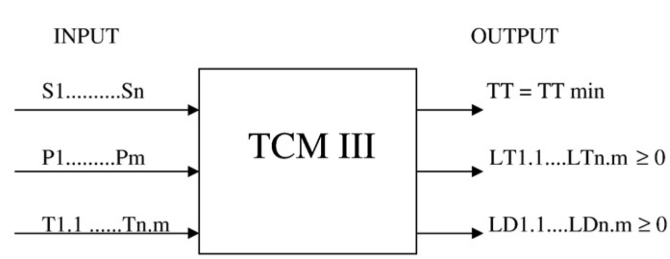

Fig. 2. Calculation scheme and output conditions for TCM III.

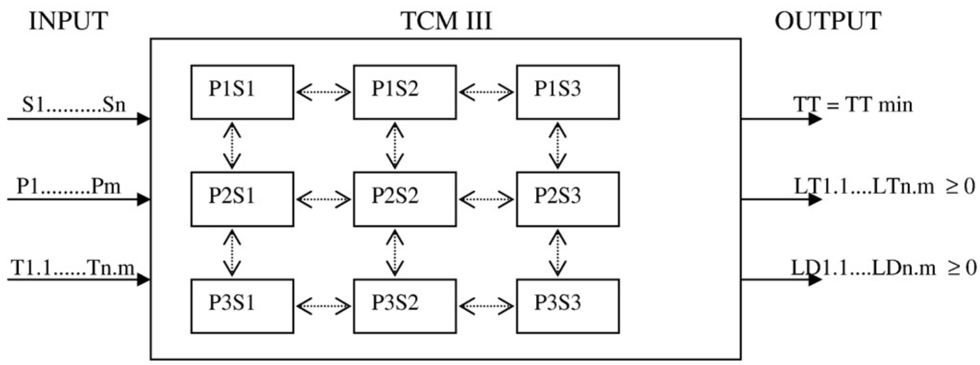

Fig. 3. Priority interdependencies in TCM III.

2.1. Comparison of algorithm properties

The genetic algorithm's principle of operation consists in creating a random population of *n* code strings made up of binary system symbols $V=\{0,1\}$ and then replicating them, interchanging chunks of strings and sometimes mutating some bits. Genetic algorithms exploit the schema (a standard describing a subset of similar strings with good solutions) theorem. Optimization calculations are performed on whole populations, as opposed to other methods in which decision variable values are sought and the possibility of finding only a local maximum is avoided.

The evolutionary algorithm's principle of operation consists in searching for the so-called global minimum through the random selection of a population of individuals (schedules). Various strategies, e.g. (1 + 1), based on mechanisms of searching sets of permissible solutions through mutation range self-adaptation, are employed. The genetic algorithm is a special case of the evolutionary algorithm. There is a predetermined constant population of individuals, on which replication is conducted. In the case of the hybrid evolutionary algorithm (HEA), first an initial population is randomly created, then the best element is found and new populations are generated. In the latter, local minima are sought, a set of them is formed and then on the basis of each new generation permutation elements to be fixed in the next generation positions are determined.

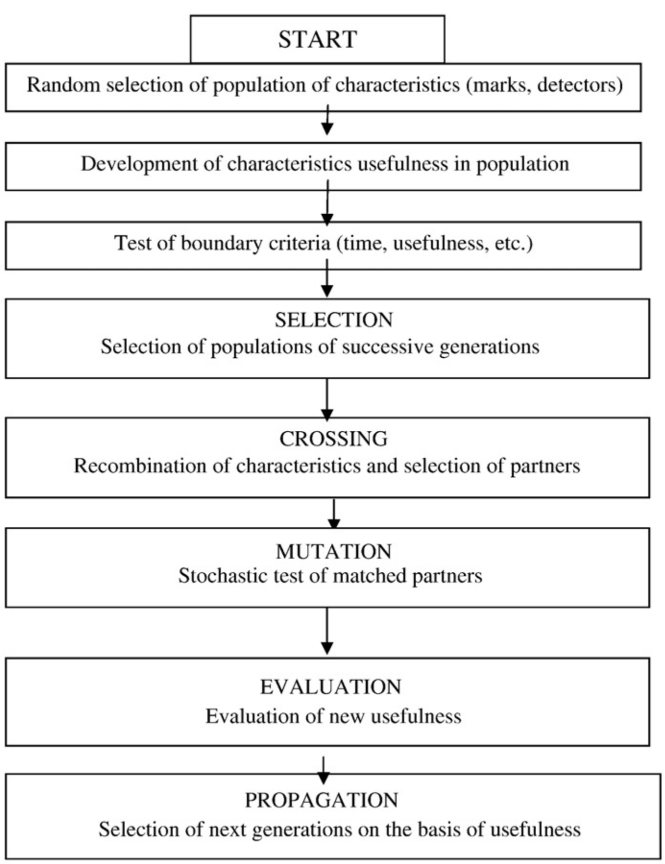

Fig. 4. Optimization using genetic algorithms [32].

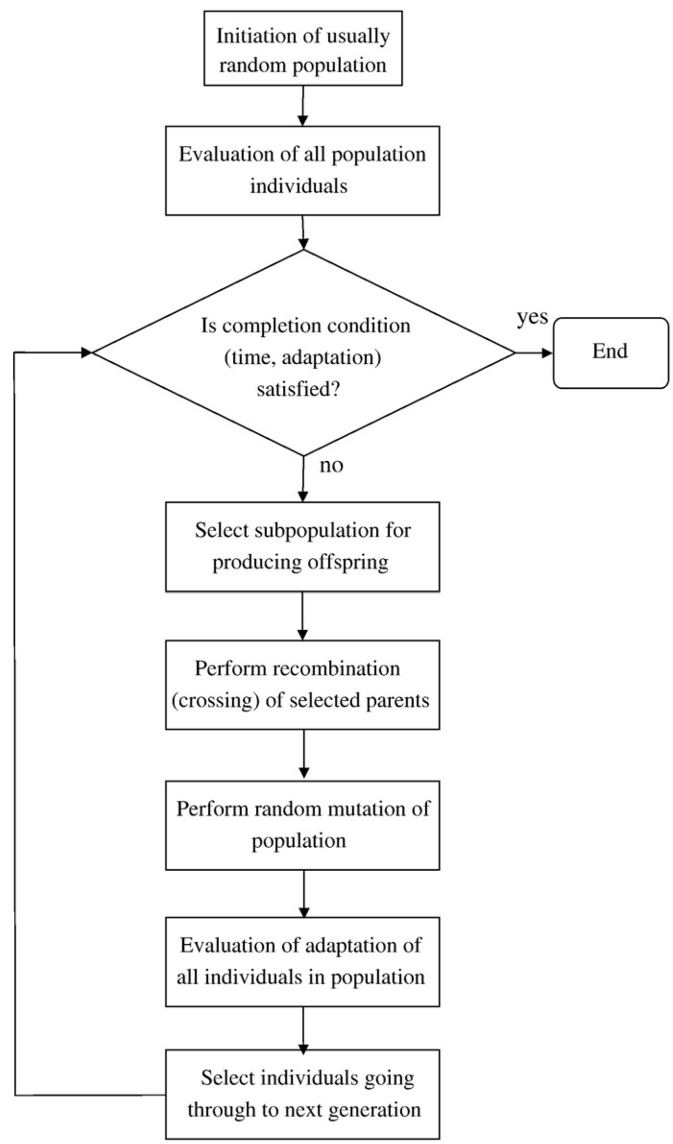

Fig. 5. Optimization process using evolutionary algorithms [33].

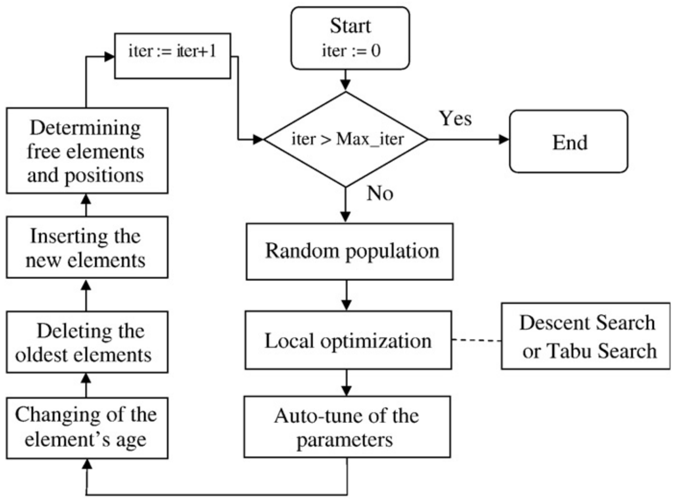

Fig. 6. Hybrid evolutionary algorithm [31].

The above optimization IT tools can be used to solve practical construction project scheduling problems, including resource requisition optimization. They do not guarantee that optimum solutions will be found but for practical purposes it is possible to significantly improve the results, using classical genetic algorithms or improved evolutionary algorithms, e.g. HEA [31]. In order to improve the optimization tools faster and more accurate algorithms of searching the space of solutions are sought. This paper presents computing test results showing that the hybrid evolutionary algorithm is highly promising for optimization applications (Fig. 5). A comparison of the computation results for the genetic algorithm and the hybrid evolutionary algorithm has shown the higher computational efficiency as described later in Section 4.

3. Hybrid evolutionary algorithm (HEA)

Hybrid evolutionary algorithm was proposed by Bożejko and Wodecki [26] and it is a general method of solving discreet optimization problems. Therefore some elements of the algorithm have to be detailed addressed to use it for solving automation problems in construction, especially the method of the problem's code for HEA, determining of set of fixed elements and local optimization approach.

The algorithm starts by forming residual population P^0 (which can be randomly formed). The best element of population P^0 is adopted as suboptimum solution π^*. Let i be the algorithm iteration number. New population $i+1$ (i.e. set P^{i+1}) is generated as follows. For current population P^i a set of local minima LM^i is fixed (by carrying out procedure *LocalOpt*(π) for each element $\pi \in P^i$). Elements occupying the same positions in the local minima are fixed (procedure *FixeSet* (LM^i,FS^i)), forming a set of fixed elements and positions FS^{i+1}. Each permutation of new population P^{i+1} has fixed elements (in fixed positions) from set FS^{i+1}. Free elements are randomly assigned to the remaining (unoccupied) positions. If there is a permutation $\beta \in LM^i$ and $F(\beta)<F(\pi^*)$, then β is adopted as permutation π^*. The algorithm stops when it has generated a predetermined number of generations (Fig. 6).

We apply following notation:

π^*: sub-optimal solution determined by the algorithm,
η: number of elements in population (the same in each generation),
P^i: population in the iteration i of algorithm, $P^i=\{\pi_1, \pi_2,\ldots,\pi_\eta\}$,
LocalOpt(π): local optimization algorithm to determining local minimum, where π is a starting solution of the algorithm,
LM^i: a set of local minima in iteration i, $LM^i=\{\hat{\pi}_1, \hat{\pi}_2,\ldots,\hat{\pi}_\eta\}$ where $\hat{\pi}_j=LocalOpt(\pi_j)$, $\pi_j \in P^i$, $j=1,2,\ldots,\eta$.
FS^i: a set of fixed elements and position in permutations of population P^i,
FixSet(LM^i,FS^i): a procedure which determines a set of fixed elements and positions in next iteration of evolutionary algorithm, ,
NewPopulation(FS^i): a procedure which generates a new population in next iteration of the algorithm, $P^{i+1}=NewPopulation(FS^i)$.

The code of the proposed hybrid evolutionary algorithm is given below.
Hybrid Evolutionary Algorithm (HEA)

Initialization: randomly formed population $P^0=\{\pi_1, \pi_2,\ldots,\pi_\eta\}$;
π^*=the best element of population P^0;
Iteration number $i=0$; $FS^0=\varnothing$;
repeat
Determine a set of local minima $LM^i=\{\hat{\pi}_1, \hat{\pi}_2,\ldots,\hat{\pi}_\eta\}$, where
$\hat{\pi}_j=LocalOpt(\pi_j)$, $\pi_j \in P^i$;
for $j:=1$ **to** η **do if** $F(\hat{\pi}_j)<F(\pi^*)$ ***then*** $\pi^* \leftarrow \hat{\pi}_j$;
Fix set
$FS^{i+1}=FixSet(LM^i,FS^i)$ i
generate new population
$P^{i+1}:=NewPopulation(FS^i)$;
$i=i+1$;
until not **S**top **C**riterion (exceeding a given time or a number of iterations).

3.1. Problem coding and notation

The problem can be defined as follows. There are: a set of n jobs $J=\{1,2,\ldots,n\}$, a set of m machines $M=\{1,2,\ldots,m\}$. Job $j \in J$, consists of a sequence of m operations $O_{j1},O_{j2},\ldots,O_{jm}$. Operation O_{jk} corresponds to the

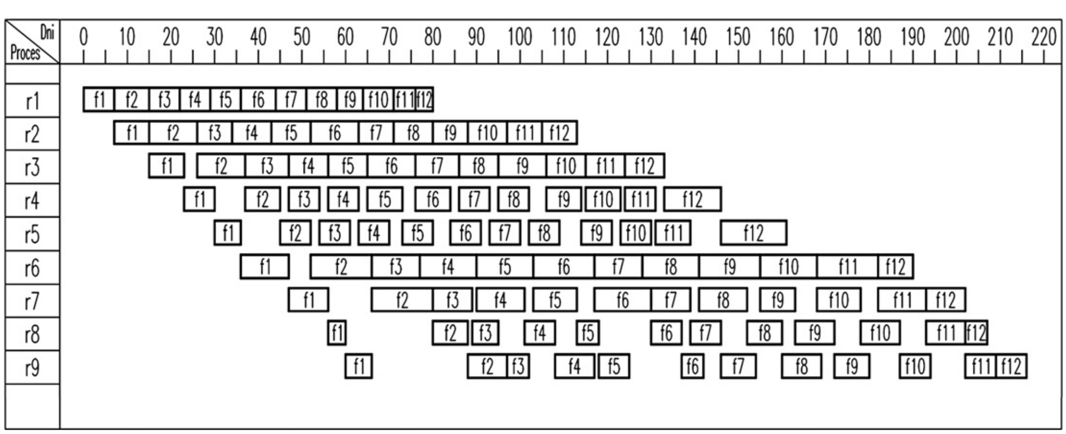

Fig. 7. Gantt chart after genetic algorithm has been applied, minimum objective function value: $f=1564.999$.

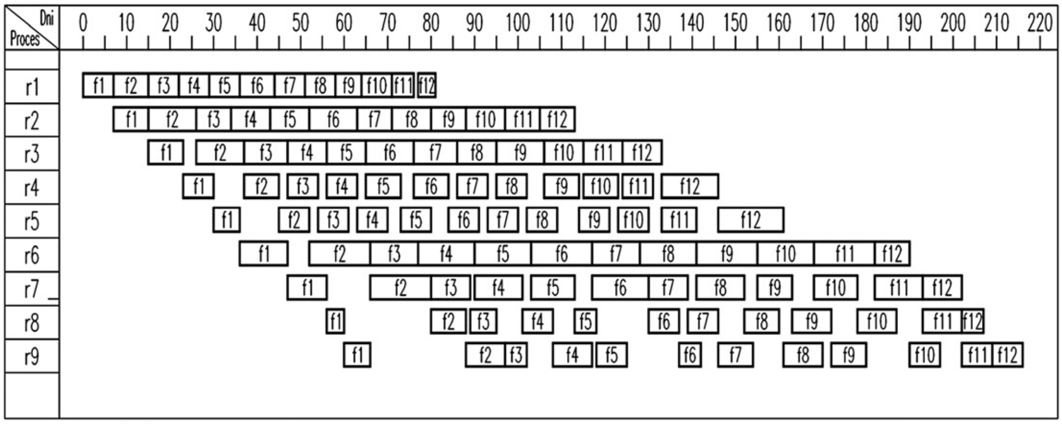

Fig. 8. Gantt chart after genetic hybrid evolutionary algorithm has been applied, minimum objective function value: $f=1508.139$.

processing of job j on machine k during an uninterrupted processing time p_{jk}. We want to find a schedule such that the maximum completion times is minimal. Such a problem is known as a flow shop problem in literature.

Let $\pi=(\pi(1),\pi(1),\ldots,\pi(n))$ be a permutation of jobs $\{1,2,\ldots,n\}$ and Π be the set of all permutations. Each permutation $\pi\in\Pi$ defines a processing order of jobs on each machine. Completion time of job $\pi(j)$ on machine k can be found using the recursive formula:

$$C_{\pi(j)k} = \max\left\{C_{\pi(j-1)k,}C_{\pi(j)k-1}\right\} + p_{\pi(j)k}\},$$

where $\pi(0)=0$, $C_{0k}=0$, $k=1,2,\ldots,m$, $C_{0j}=0$, $j=1,2,\ldots,n$.

3.2. Local optimization (procedure LocalOpt)

3.2.1 Local search method

The local search (LS) method is a metaheuristic approach designed to find a near-optimal solution of combinatorial optimization problems. The basic version of LS starts from an *initial solution* x^0. The elementary step of the method performs, for a given solution x^i, a search through the *neighborhood* $N(x^i)$ of x^i. The neighborhood $N(x^i)$ is define by move performed from x^i. A move transforms a solution into another solution. The aim of this elementary search is to find in $N(x^i)$ a solution x^{i+1} with the lowest cost functions. Then the search repeats from the best found, as a new starting solution.

Local search algorithm

Select a starting point: x; $x_{\text{best}}:=x$;
repeat
Select a point $y\in N(x)$ according to the given criterion based on the value of the goal function $F(y)$;
$x:=y$;
if $F(y)>F(x_{\text{best}})$ ***then*** $x_{\text{best}}:=y$;
until some termination condition is satisfied;

A fundamental element of the algorithm, which has crucial influence on quality and time of computation, is a neighborhood. A neighborhood is generated by the insert moves in the best local search algorithms with the permutation representation of the solution.

3.3. A set of fixed elements and position (procedure FixSet)

A set of fixed elements and positions FS^i (in ith iteration of the algorithm) consists of quads (a,l,α,φ), where a is an element of the set N $(a\in N)$, l is a positions in a solution $(1\le l\le n)$ and α, φ are attributes of a pair (a,l). Parameter α means *fitness* and decides on belonging to the set, φ is an *age* — element is removed from the set after exceeding some number of iterations (here: 3 iterations).

In every iteration of the algorithm, after determining the local minima (procedure *LocalOpt*), a new set $FS^{i+1}=FS^i$ is established. Next, a *FixSet*(LM^i, FS^i) procedure is called, in which there are executed the following operations:

(a) changing of the age of each element,
(b) deleting the oldest elements,
(c) inserting the new elements.

3.3.1 Inserting elements

Let $P^i=\{\pi_1,\pi_2,\ldots,\pi_\eta\}$ be a population of η elements in iteration i. For each permutation π_j from P^i, applying the local search algorithm

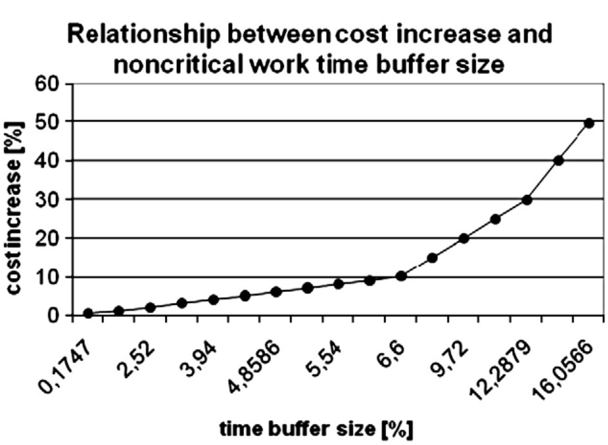

Fig. 9. Noncritical work time buffer size versus additional costs.

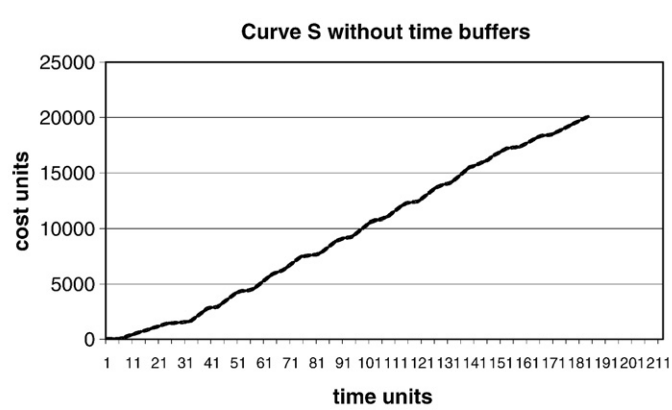

Fig. 10. Cost versus time for latest noncritical work dates.

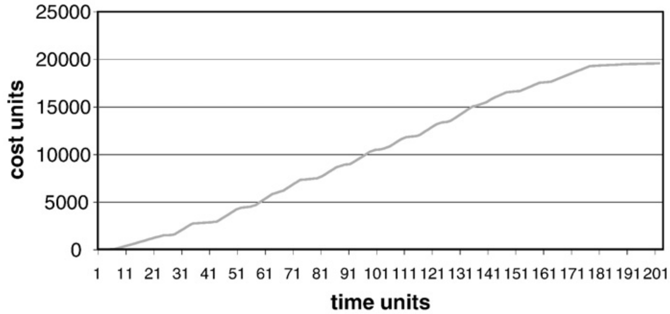

Fig. 11. Cost versus time for assumed total cost increase of 2.5%.

($LocalOpt(\pi_j)$ procedure), a set of local minima $LM^i = \{\hat{\pi}_1, \hat{\pi}_2, \ldots, \hat{\pi}_\eta\}$ is determined. Each permutation

$\hat{\pi}_j = (\hat{\pi}_j(1),\ \hat{\pi}_j(2), \ldots\ \hat{\pi}_j(n)),\ j = 1, 2, \ldots \eta.$

Let

$nr(a, l) \geq |\left\{ \hat{\pi}_j \in LM^i :\ \hat{\pi}_j(l) = a \right\}|.$

It is a number of permutations from the set LM^i, in which there is an element a in the position l. If $a \in N$ is a free element and $\alpha = \frac{nr(a,l)}{\eta} \geq \Phi(i)$ then the element a is fixed in the position l.

3.3.2 A new population (procedure NewPopul)

To generate a new population P^{i+1}, randomly drawn free elements are inserted in remaining free positions of the elements of population P^i.

NewPopulation(FL_i)
$Pi^{+1} \leftarrow \emptyset$;
Determine a set of free elements
$FE = \left\{ a \in N : \exists(a, l, \alpha, \varphi) \in FS^{i+1} \right\}$
And a set of free positions
$FP = \left\{ l : \exists(a, l, \alpha, \varphi) \in FS^{i+1} \right\}$;
for j: = 1 **to** η **do** {*Inserting of fixed elements*}
for each $(a,l,\alpha,\varphi) \in FS^{i+1} \pi_j(l) := a$;
$W \leftarrow FE$;
for s: = 1 **to** n **do** {*Inserting of free elements*}
if $s \notin FP$ **then**
$\pi_j(s) = w$, **where** $w = random(W)$ a**nd** $W \leftarrow W \setminus \{w\}$;
$P_{i+1} \leftarrow P_{i+1} \cup \{\pi_j\}$.

Function *random* generates from a uniform distribution an element of the set W. Computational complexity of the algorithm is $O(\eta\ n)$.

4. Optimization computations

Time/cost optimization in TCM can apply to:

- the minimization of resource costs for the assigned construction project lead time,

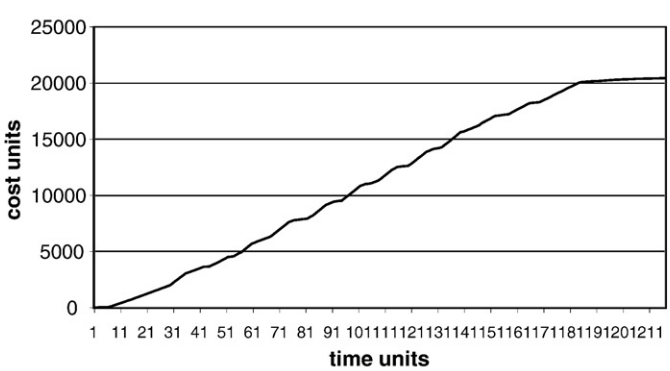

Fig. 12. Cost versus time for assumed total cost increase of 5%.

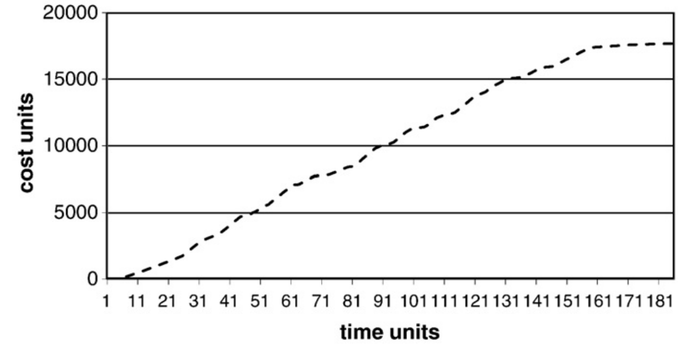

Fig. 13. Cost versus time for assumed total cost increase of 10%.

- the determination of the total increase in construction project costs depending on the time buffer size for the assigned construction project lead time.

4.1. Case I

The first of the above optimization tasks consists in minimizing the resource costs (uniform worker employment costs) for the assigned construction project lead time (the employment level optimization problem is presented in a paper by Rogalska et al. [34]). One of the optimization criteria consists in taking the average resource requisition value into account in the constructed objective function. When searching for the minimum value, the average deviation from the daily demand can be adopted as the measure of resource (demand for workers) cost nonuniformity.

Objective function:

$$f(x) = \frac{1}{T} \sum_{j=1}^{T} \left| \frac{q_j(x) - r_{avg}}{r_{avg}} \right| \tag{1}$$

where

$$r_{avg} = \frac{1}{T} \sum_{i=1}^{n} d_i r_i \tag{2}$$

is the average resource cost (the average number of employed workers) in each of the T days.

$x \in R^n$

$x = (x_1, x_2, \ldots, x_n)$ the vector of task execution start instants;

$x_i \in [a_i, b_i]$

a_i	the earliest moment of task i execution commencement,
b_i	the latest moment of task i execution commencement,
$q_j(x)$	the number of persons employed on day j, $j = 1,2,\ldots,T$, T — a time horizon,

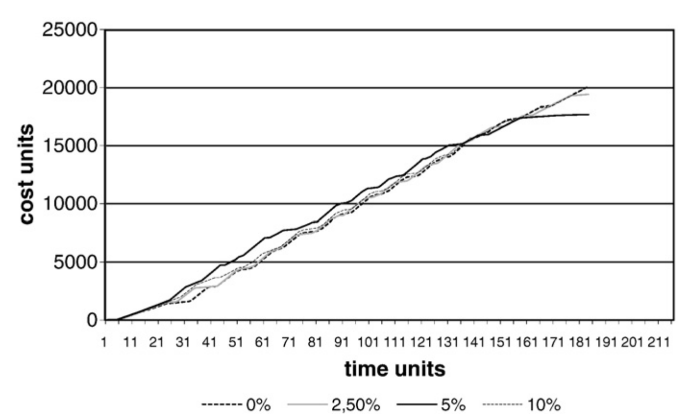

Fig. 14. Time/cost curves S for additional costs of 2.5%, 5%, 10% for latest work commencement dates (0%).

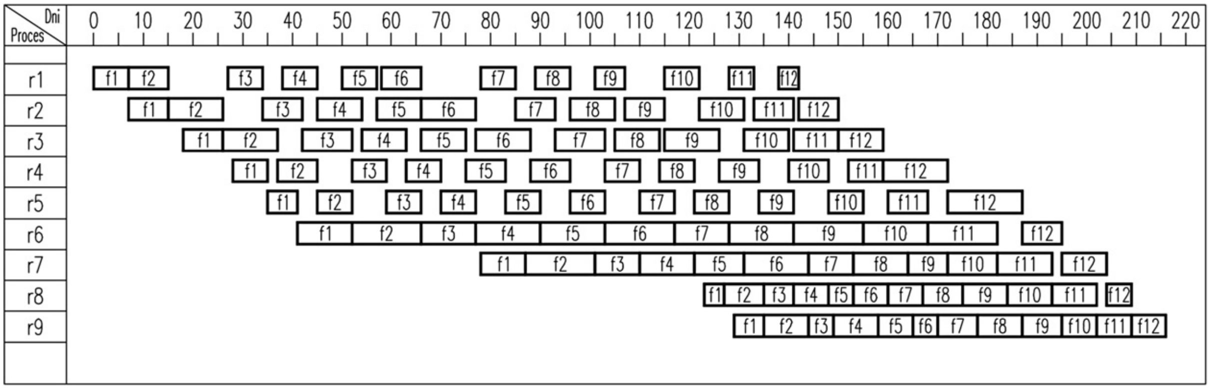

Fig. 15. Schedule according to latest dates.

d_i duration of process i,
r_i the number of persons employed to carry out process i.

In order to carry out optimization computations one must determine the objective function for each iteration, searching for the lowest value.

The numerical data for the computations are for 12 building structures on which 9 construction processes are to be carried. The project is represented by a matrix of construction process (p=9) durations for the building structures (f=12).

$$T=\begin{Bmatrix}\{7,8,7,7,7,8,7,7,6,7,5,4\};\{8,11,8,9,9,11,8,9,8,9,8,8\};\\ \{8,11,10,9,9,11,10,9,11,9,9,9\}\\ \{7,8,7,7,8,8,7,7,8,8,8,7,13\};\{6,7,7,7;7,7,77,7,7,8,15\};\\ \{11,14,11,13,13,14,11,13,14,13,14,8\}\\ \{9,14,9,11,10,13,9,11,8,10,11,9\};\{4,8,6,7,5,7,7,8,9,9,9,5\};\\ \{6,9,5,9,7,5,8,9,8,7,7,7\}\end{Bmatrix}.$$

The work duration matrix was developed on the basis of take-offs for a complex of residential buildings, taking into account the resources. TCM III was used to determine the construction project realization cycle (T=216 working days). The method allows one to identify a sequence of critical processes and to determine the commencement and completion dates for noncritical works. Since the positions of the works can be moved on the time axis one can optimize the resource (employment) costs according to the adopted objective function.

After 100,000 iterations the objective function values: f=1564.999 (0.312375 as the average percentage deviation ensuring direct (resource) cost uniformity for all the T days) and f=1508.999 (the average deviation: 0.301198) were obtained for respectively GA and HEA (Figs. 7 and 8). Thanks to the use of HEA the result improved by 3.57%.

4.2. Case II

The second optimization case consists in determining the total increase in construction project realization costs versus the time buffer size for the assigned construction project lead time. The cost analysis and control are often performed using graphical construction cost cumulation in the form of S curves, whereby one can analyze the increase in construction project costs depending on the time buffers.

4.3. Problem formulation

The starting point for the analysis is a situation when construction works are carried out as late as possible, i.e. the aim is to invoice and pay for the works as late as possible. In CPM/PERT and TCM III the positioning of works at the latest dates on the time scale makes all the works critical and devoid of time reserves (buffers) which would compensate for any disturbances in performing the works. Carrying out works at the earliest dates results in earlier (than necessary) payments to the contractors for the work done and contributes to an increase in project financing (e.g. credit) costs. An attempt was made to examine the contribution of noncritical work time buffer size to an increase in construction project (additional) costs. The interdependencies involved are expressed by a multicriterial objective function. In practice it becomes necessary to determine the best work commencement dates for the adopted criteria (in the form of an objective function) in a time interval calculated in a standard way.

Optimization calculations were calculated using HEA. The algorithm makes it possible to determine noncritical work commencement dates for conditions expressed by an objective function.

Objective function:

Let us assume that works assigned by permutation π are to be carried out. The works will be financed by a credit in amount D available in tranches. The objective function value corresponding to

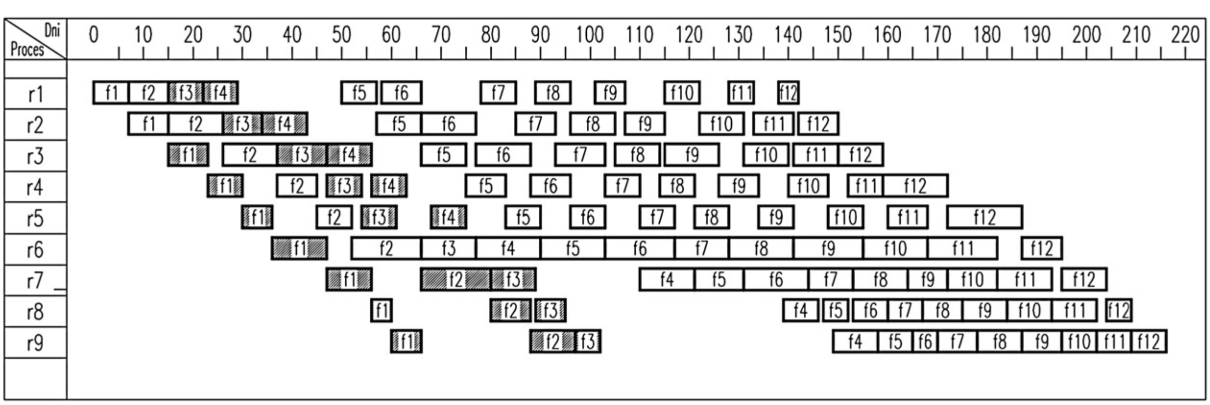

Fig. 16. Schedule according to latest dates for buffer of 5%.

the financing of the excess (additional cost) above the available total tranche amount is:

$$F(\pi) = \sum_{i=1}^{T} \max \quad \{0, c_\pi(i) - t(i)\},$$

where

$c_\pi(i)$ the total work cost on day $i=1,2,\ldots,T$ for the work order assigned by permutation π,

$t(i)$ the tranche value on day $i=1,2,\ldots,T$, e.g. when the credit for amount D is divided into four equal tranches

$$t(i) = \begin{cases} 0 \quad \text{dla} \quad i < \frac{T}{4}, \\ \frac{D}{4} \quad \text{dla} \quad \frac{T}{4} \le i < \frac{2T}{4}, \\ \frac{2D}{4} \quad \text{dla} \quad \frac{2T}{4} \le i < \frac{3T}{4}, \\ \frac{3D}{4} \quad \text{dla} \quad i \ge \frac{3T}{4}. \end{cases} \quad \text{for}$$

Similarly as above, the optimization computations are performed for numerical data on a complex of 12 building structures on which 9 construction processes are to be carried out. The project is represented by construction process duration matrix $[T]$ of size 12×9, i.e. 12 rows ($f=12$ building structures) and 9 columns ($p=9$ processes). The matrix elements are based on take-offs for constant resources. TCM III was used to determine the construction project realization cycle ($T=216$ working days).

The optimization computation results are illustrated in the diagrams below (Figs. 9–16).

5. Conclusions

The paper presents an analysis of the time/cost relationship, performed using time coupling method TCM III. A modified hybrid evolutionary algorithm (HEA) developed by Bożejko and Wodecki [31] was used for optimization. From the construction practice's point of view the TCM development is done in order to adapt the method to the TOC (the Theory of Constrains — elaborated by Goldratt E.) with taken into account CCS/BM (method of the Critical Chain Scheduling/Buffer Management) and also to take into account randomness, risk and uncertainty of the activities duration, and modified algorithms for construction project management optimization.

The optimization computations were performed on a 3 GHz Intel Pentium IV computer for the numerical data on a selected construction project of size 12×9, i.e. for 12 building structures and 9 construction processes to be carried out on them. Time Coupling Method TCM III was used for scheduling and the result: $T=216$ units was obtained. The relationship between additional construction project realization costs generated as a result of the difference between the actual work commencement dates and the latest work commencement dates was examined. The results, presented above in the form of diagrams, are for total quantities.

Assuming permissible additional costs (amounting to, for example, 1%, 2.5%, 5%, 10% and 15%) resulting from work completion at dates different from the latest dates and using TCM III [24–26] and hybrid evolutionary algorithms one can determine the best (in terms of the adopted objective function) construction work commencement dates. The basic numerical data and the computation results can be found at http://wojciech.bozejko.staff.iiar.pwr.wroc.pl/source.

In further research we want to apply presented ideas to other problems of construction practice and other criterion functions, for which optimal algorithms are powerless.

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