SCHEDULING CONSTRUCTION OF A LARGE SCALE WATER-PROOF REINFORCED CONCRETE FOUNDATION SLAB

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Abstract

Having the maturing pool of electronic computing tools elder questions of their ability are re-emerging. Questions can be summarized as: What a situation can an automated system substitute human decision makers in ? What a situation may an automated system substitute human decision makers in ? Utilities of even the latest high-tech computer applications proved to be far insufficient to solve some scheduling problems characterizing every-day challenges of construction industry. The paper introduces a short story of such a situation, a story of a need-born computer application aiming to help design and scheduling tasks of constructing a large-scale water-proof reinforced concrete foundation slab.

Keywords : construction technology, operations research, computer applications

INTRODUCTION

Nowadays we've got used to be obeyed and fascinated by abilities and capabilities of up to date computer techniques from simple numeric problems through extended experts' systems, data bases, automated behaviour simulations, up to 3D telemetric- or multi-media applications. While further unpredictable development possibilities of digital computer technology make us suspect an all-mighty tool, frontiers of its capabilities relentlessly reveal from the dark. You could think of the „some" mathematical problems have been remained unsolved despite of having the magic tool and stubbornly standing against the so spectacular ways of developments. The age-old human algorithms still have their roles, having been at most „supported" by the artificial intelligence.

One of these stubbornly resisting problems is known in mathematics as „factorial- or combinatorical boom", to be faced against at sequencing (scheduling) jobs in Construction Industry. Sequencing problems of these kinds are tipically by-passed in building practice, or used to be „resolved" in some evidential ways. For example: In case of sequencing performances of more buildings individual contracts usually freeze all possibilities even at start – though thinking in regional extent or in infrastructural context could give stakeholders gains more tens of percents higher either in cash or in time occasionally. Or: Order of technological processes usually is set by experiences and by traditions of applied technology – like considerations of managing the site or directing available resources – while in some special cases holy traditions would be better revised.

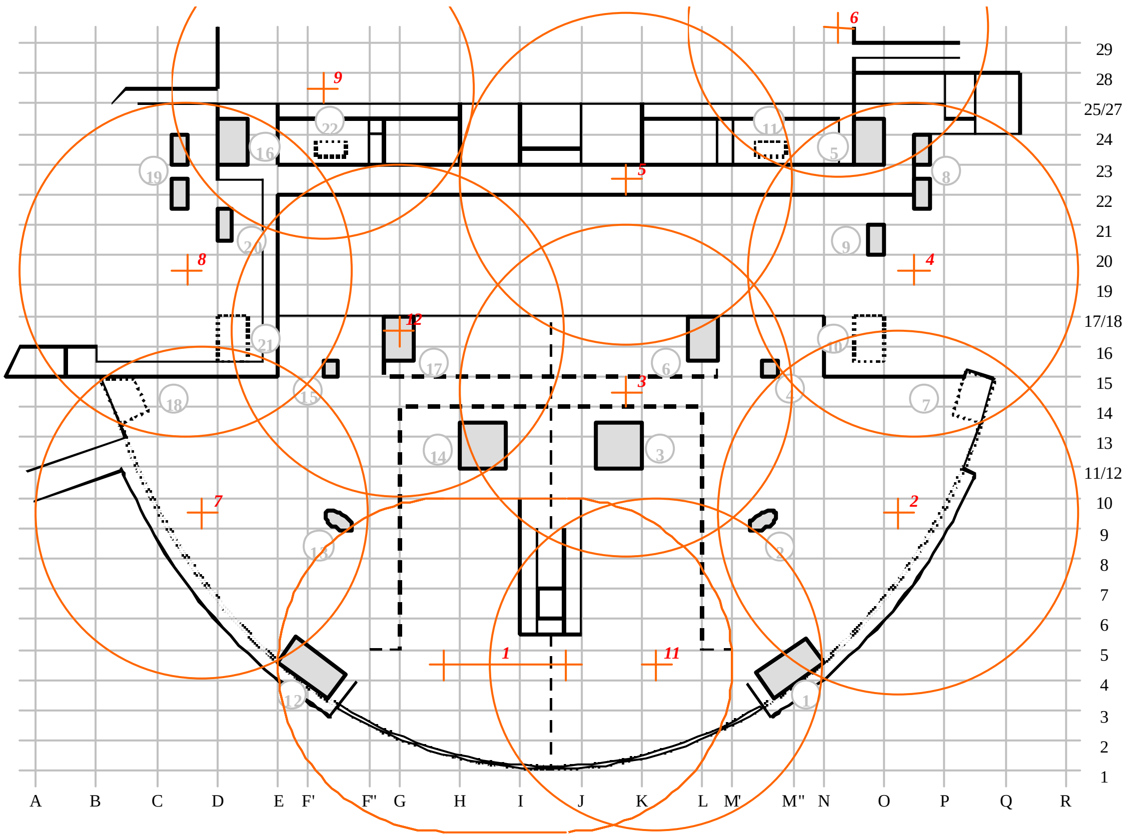
There exist some technological sequencing problems at which due to manifold factors and circumstances to find the most appropriate solution may become a great challenge, especially when decision maker has strictly limited time to pay for it. Problems seemingly summarized in a simple way may grow heavy difficulties for which to find solution algorithms may have difficulties even in pure mathematics too. The paper below tells a short story of development and application of a computer software titled by its users as „a game" and brought to existence in such a heavy situation.

THE PROBLEM

Late May of 2001 senior managers of the main contractor (STRABAG Building Ltd. 48. Dir.) requested the Department Of Construction Technology And Management of Budapest University Of Technology And Economics (BUTE) to cooperate in developing time schedule of structural works of cultural and trade center called „Asia Center" to be built by their company nearby an elder shopping center called „Polus Center" at Szentmihályi street in 15^{th} District of Budapest. Request was necessiated by the strictly limited time frames and by technical and managerial problems forseen by experts of the company. At that time dewatering and deep foundation works had been under progress according to which – as a sub-job – a so called „White Basin" an unfragmented full area water proof R.C. foundation slab and its R.C. perimeter walls were to be built.

Measures were astonishing. At Phase I – representing about 60 percent of the overall construction job: Capture frame of the 0.8 m thick R.C. foundation slab had been constructed in one single phase with no extension joints below the two floory full area basement was a 240 x 200 m sized rectangle. For structural works 11 tower cranes of 45 m reach and of 6.5 ton lifting capacity were provided, temporarily complemented with auto cranes. Ready-mixed concrete was produced by a mixing plant of 70 m^3/h (~1000 m^3/day) capacity, located on site. During construction of the partly monolithic partly pre-fabricated structure for to build the monolithic structures only some 90.000 m^3 insitu concrete was poured. Pre-fabricated elements were transported on wheels from Hódmezovásárhely, Dunakeszi, Paks, and Dunaújváros, according to a daily schedule of production and of delivery. Scheduled completion time was 18 months.

Measures of the overall building (Phase I and Phase II together): Lot area below the building: 64.000 m^2. Floors: 2 floors of full area basement, ground floor, 3 upper floors with green roofs and with a mezzanine for building facilities between floor 3 and floor 4. Clear height of upper floors: 5 m. Total built area: 210.000 m^2. Budgeted cost of building works: US$ 130.0 million, not considering rental finishes and further expences and charges associating.



Picture 1.; Asia Center, Construction Phase I. („Son" and „Daughter" Buildings) structural works, Crane layout plan (STRABAG Building Ltd. 48. Dir.)
Grid in background indicates 16 x 8, and 8 x 8 m raster of piers' layout

THE JOB

One sub-task according to the cooperation aggreement between the contractor and the University was to develop a detailed time schedule of constructing the water proof R.C. foundation slab broken down to daily concreting units (blocks) with main emphases on :

- Shrinkage of large-scale R.C. structure under construction (expectations on water proofing, block formations, extents and sizes);
- Technology of performance (sub-processes, phases and their time needs);
- Available capacities of resources (day by day quantities scheduled);
- Accesses to blocks to be constructed actually (material flows, building traffic);
- Schedule preferences on some blocks of high importance (crane footings, slip-forms);
- Non-directed relative lag-times of neighbouring blocks (water sealing capability versus in-progress shrinkage, water sealing facilities);
- Further structural elements to be erected on blocks (upper structure);
- On-going progress of structural works as access barriers to blocks to be built actually (providing accesses for sub-contractors);
- Strictly limited dead-lines (eliminating breaks and time losses).

Breaking down the large-scale structure to dailly constructed blocks together with reinforcement designs (fitting pieces) of individual blocks (after getting the daily schedule of performance) was elaborated by engineers of UVATERV Corporation.

Within this sub-task university experts were charged to check detailed schedule (sequence) of performance proposed by engineers of contractor, and to elaborate methodology for scheduling and planning similar large-scale foundation slabs such as the one under Building „Father” at „Asia Center” to be erected during Phase II of the project.

THE MODEL

To handle relative positions (adjacences) of blocks it was Graph Technique that proved to be the most appropriate tool of mathematics. Applying it it got be handy to set inter-locational relations and relative time restrictions. But graph (network) techniques and algorithms available – such as network techniques for scheduling, e.g.: CPM, PERT [1] – proved to be improper due to their predestined manner of handling so called Directed Graphs. (It is necessary to set in advance unambigously which neighbouring element must be constructed first and which others later ... though in our case it is part of the question itself.)

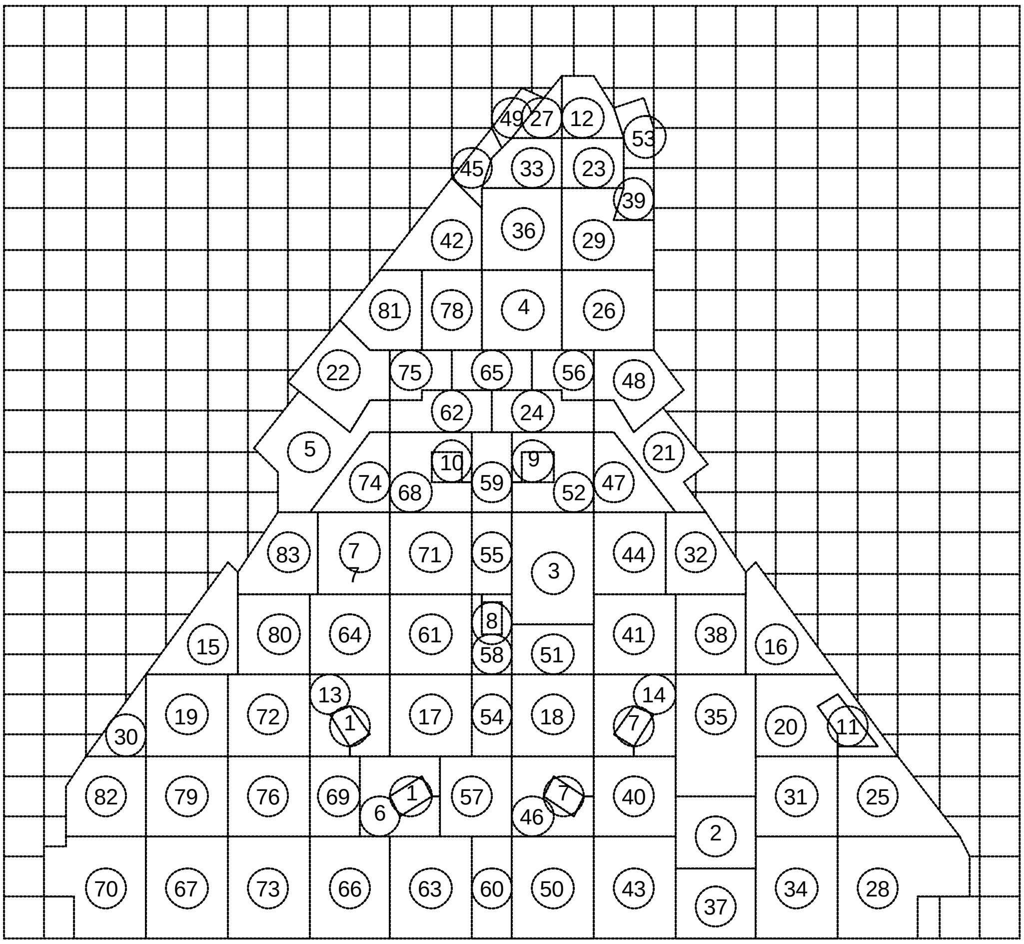
Scheduling (Sequencing) Problems on the other hand are age-old well-known „Hard-Boys” of Operation Research (Applied Mathematics). Having mechanized and automated production systems wide-spread lots of their (i.e. of sequencing) variants and sub-variants had been specified in lots of different manufacturing environments [2]. With expectations of some rare fortunate situations to develop solutionary algorithms (i.e. solution convergence of which is not or slightly dependent on the extent of the actual problem) has been stayed open possibility for research. At the rest of identified problems of this kind mainly some variants of enumerative methods (Branch&Bound, Partial Enumeration) are available. Though they are exact, their speed of finding solution is highly (exponentially or factorially) dependent on the extent of the actual problem.

To demonstrate difficulties:
Number of all possible sequences (repeatless permutations) of three elemets (e.g. „A”, „B”, „C”) is 3!=6 („ABC”, „ACB”, „BAC”, „BCA”, „CAB”, „CBA”). For four elements this number is 4!=24. For five elements 120, for ten more than 3.6×10^6 and for twenty elements it is more than 2.43×10^{18}. That is: If we wanted to list all possible sequences of twenty elements (with no sequence excluded from examinations in advance) and we had a computer listing a million of these sequences (i.e. schedules) in a second, we would stay more than seventy-seven thousand years (!) in front of the computer before we get all possible sequences listed. But we have no such a long time and the number of elements to be scheduled is generally far more than twenty.

We have some slight scraps of comfort having the fact that in the rest of real situations we may exclude some sequences off the overall examinations in advance. But methodically it can’t be stated.

Using specification system suggested by some authors (Graham, Lenstra, Lawler, Rinnooy Kan, NATO Advanced Study and Research Institute Report, 1981 [2]) the problem could be coded as $F|G,abs(\Delta C)|C^{max}$. That is: The job is to find an optimal sequence and optimal schedule (F) of „n" elements aiming the shortest overall completion time (C^{max}) while non-directed minimum lag times for adjoining elements are given in absolute value ($abs(\Delta C)$). Restrictions of this latest kind are set in a non-directed weighted graph G[A,N,τ].

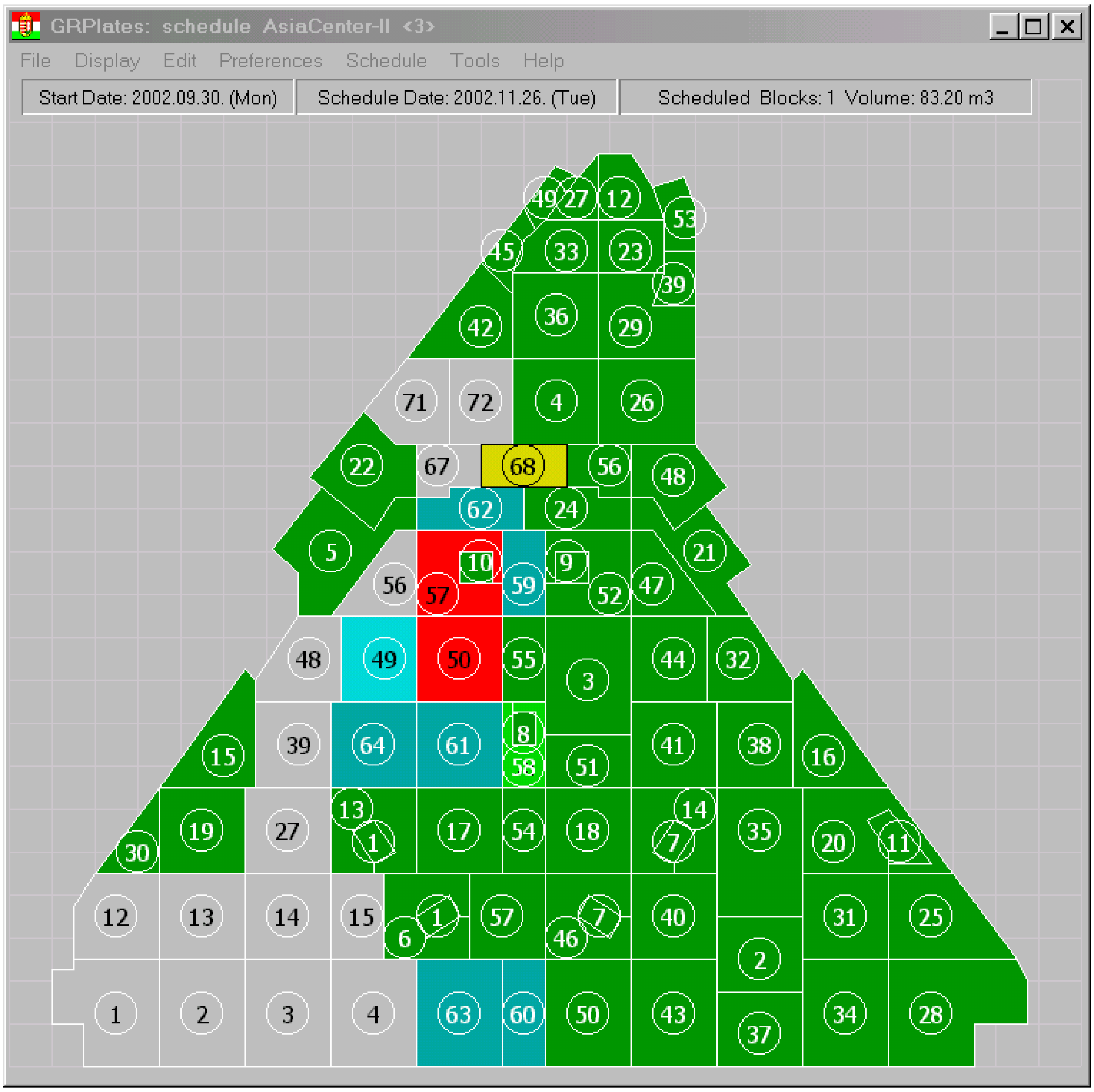
THE „GAME"



Picture 2 Asia Center, Phase II. („Father" Building) water proof R.C. foundation slab, block design and schedule proposal (to be approved). Background grid reflects 8 x 8 m raster of piers.

Considering factors like estimated time necessary for detailed researches, aimed short-term practical use declared in the request as developing a time schedule and aiding planning jobs and also considering missing tools for testing expected results of a long-term research it came the decision to develop a quick access practical aid in form of a test program.

To assist human decision makers and evaluations and to promote development of scheduling tasks a graphical computer program titled „GRPlates" had been developed in an approximately two weeks period. The software developed in Delphi language in Windows environment provided graphical interfaces for to break down the original structure to daily scheduled blocks and for to develop the most appropriate detailed schedule for construction.



Picture 3 Daily schedule in colors (non-directed relative lag-time 3 days):

white figure	: scheduled relative time position of block
black figure	: identifier of block
gray	: non-scheduled block (being to be scheduled yet)
dark green	: block finished (before day 58)
light green	: block actually under construction (day 58)
yellow	: block schedulable earliest to day follows (day 59)
red	: block forbidden on actual and on following day (days 58, 59)
light cian	: block still schedulable on actual day (day 58)
dark cian	: block already scheduled on later days (after day 58)

First job of designer is to develop a pre-liminary break-down plan called „blockage” or „configuration” (i.e. planning configuration of daily constructed blocks) originated from existing drawings of the structure and of its details such as footings, elevator towers, piers, walls, extent-limitations, etc.. For this essentially drawing job a traditional graphical screen is provided with almost all usual functions (copy, rotation, move, etc.) of a graphical editor. As the result of this job a grapical configuration of attached polygons (representing daily constructed blocks) is available for the next phase of planning. Built-in recognizing algorithms automatically generate – and optionally display – the restrictions' graph (G[A,N,τ]) based on the configuration plan and on pre-set minimum lag time (abs(ΔC)).

From that point the software works as an immediate interactive display assisting the „What would be if …" mannered problem-solving efforts of the user (designer). After assigning date of a block scheduled – i.e. assigning block clicked to actual date of schedule – stepping forward or keeping actual date get be processed according to the user's commands automatically. During scheduling job colors of blocks updated automatically are indicating possibilities and offers for the designer, such as blocks free or forbidden to schedule to actual- or following days of time-plan, together with other blocks being scheduled or still being to be scheduled. Work of designer in this planning phase could be best characterized as coloring a painting book like the game for young children. Built-in algorithms permanently display quantity of material scheduled to actual date of time-plan in units set by the designer, together with relative and calendar position of scheduled days having been assigned to individual blocks.

During this problem-solving job it is possible to return time by time to the drawing phase and to re-design configuration in ways of reshaping, splitting or uniting blocks. Designer also has ways of assigning more blocks to the same day (e.g. considering more sub-contractors) together with either partly or fully withdraw shedules assigned. According to pre-set options of the program it is possible to hurt the rules of design temporarily, that is to assign so called „forced schedules" with shorter lag-times, that serves well in case of blocks attached slightly (at a corner only) or having less significance. Having the schedule completed a graph in colors indicating valid, broken or so called „passive" time-restrictions can be optionally displayed in similar ways that have been used at highlighting critical paths of network-typed time-models.

Final result of problem-solving job is the configuration design and its schedule together. Results can be either exported or saved as vector-graphics (*.wmf) for further processing or for documentation purposes. Having the configuration design and ist schedule detailed design of reinforcement within the blocks can be completed. Having the schedule itself foreset progression of performance can be displayed as a kind of animation on the screen of the computer.

Having the software under progress (not ready for sale), and considering it's original destination of being an aid for research, together with it's operational manual it has been handed over free of charge to the experts of the contractor STRABAG Building Ltd. with restrictions of application mainly for testing purposes and at construction project denominated in the request only.

„SERIOUSLY”

First hard mission of the „game” had been launched after an unexpectedly short testing period during preliminary planning of Phase II („Father” Building) of Asia Center Project. Engineers of UVATERV Corporation requested the author for to let them apply the software at their job while elaborating detailed drawings of the large-scale reinforced concrete foundation slab.

As a frame for the software's application a special research agreement was signed under between the designers and the author. By the means of the agreement the author was charged with processing and transforming the configuration scheme of the slab set by the designers and with managing a short training or tutoring course aiming the operation of the software. The author also handed over the software and it's documentation with restricting the application to the specified project. During the cooperation initial schedules were set by the designer and by the author hand in hand, while in later phases smaller but frequent modifications of drawings and of schedules necessiated by circumstances revealed during progress of work were elaborated by the designers.

According to the agreement engineers and designers are to summarize their practical experiences about using the software and to submit offers and suggestions on built-in algorithms for further developments promoting the long-term research of the problem. Also according to the agreement the author is permitted to cite configuration schemes elaborated during the project by the designers as demonstrations in his publications (like this one) with unambiguos references to the designers.

It is irony of fate that – due to some marketing and financing aspects – works of Phase II of project got be postponed by the investor to a later phase by the time pre-set proportion of finished Phase I would get turn to account. …

The problem itself has been stayed open for researches. When setting the model of the problem lots of variants or individual questions can be specified. Such as:

- ✍ Having a given design, daily available resources and minimum lag-time what is the shortest overall execution time of building a given configuration ?
- ✍ Having a given design, daily available resources and deadline for the overall execution what is the maximum lag-time for building the given configuration ?
- ✍ Having the deadline for overall execution and the minimum lag-time set by technology how to design the configuration and what are the needed (resource) capacities ?

At modelling problems of these kinds further difficulties may emerge when pre-set schedule preferences (such as: preferred blocks, forced assignments – see: Coloric Graphs, Cartography) also become significant part of the problem. …

THE DECISION MAKERS

„Asia Center” Construction Project, Phase I. („Son” and „Doughter” Buildings), structural works, and Phase II. („Father” Building), preliminary planning :

G. Matusek, regional director, STRABAG Ltd. 48. Dir., senior project manager;
J. Lázár, senior engineer, STRABAG Ltd. 48. Dir., project manager;
R. Varga MBA, senior site engineer of structural works, STRABAG Ltd. 48. Dir.;
Cs. Petho, senior engineer, UVATERV Corp., R.C. foundation slab, detailed plan;
E. Tatai, engineer, UVATERV Corp., R.C. foundation slab, detailed plan;
Dr. Z. A. Vattai, BUTE DOCT&M, software development and consultation.

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