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PRODUCTIVITY IMPROVEMENT AND DEVELOPING FRAMEWORK FOR ROADS MAINTENANCE: A CASE STUDY OF JOHANNESBURG ROADS AGENCY AND ETHEKWINI METROPOLITAN MUNICIPALITY

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Abstract

Municipalities in South Africa (SA) are battling to maintain their roads infrastructure utilising internal maintenance teams. The greatest concern among municipal staff seems to be a perceived lack of long-term performance and maintenance data (R. Lukes & C. Kloss, 2008). Several municipalities are struggling to operate and maintain their infrastructure in a cost-effective manner (IMESA, 2012). These municipalities are not providing enough maintenance budget for operations and maintenance which leads to poor infrastructure maintenance and resulting into ever ending infrastructure backlogs. There is a long turnaround time in attending to service requests in these municipalities and this might lead to potential accidents when repair work takes longer. There is also lack of efficiency and effectiveness to improving productivity by municipal maintenance internal teams
The developed framework standards for operation and maintenance of roads infrastructure for municipal teams will reduce turnaround time in attending to service requests, improve productivity and assist government allocation of resources per maintenance work activity. This will lead to systematic way of attending to maintenance work ensuring over 80% utilization of resources (plant, labour and material) and reduced wastage and idling time.

Keywords: capacity improvement, productivity improvement, roads maintenance framework, roads maintenance standards.

1. Introduction

There are eight metropolitan municipalities in South Africa (SA), namely: The City of Johannesburg Municipality, the City of Tshwane Municipality, the City of Ethekwini Municipality, the Buffalo City Municipality, the Mangaung Municipality, the City of Cape Town Municipality, Nelson Mandela Bay Municipality and the City of Ekurhuleni Municipality. The population that resides in these metropolitan municipalities is estimated at 33,7% of the entire SA population (Stats SA, 2016). These municipalities are at the centre of how South African citizens experience government services delivery. Governance is facilitated by a number of key infrastructures, the one being the road infrastructure network. This road network is the key enabling infrastructure where citizens move from one point to the next utilising different modes of transport. Part of the municipality’s core mandate relating to road infrastructure is planning, designing and improving the system of movement in the city’s streets, sidewalks and road intersections, including the traffic signal control system, to ensure safety and efficiency.

There is a need to direct limited resources from municipalities to address the most critical needs thereby achieving a balance between maintaining and renewing existing infrastructure whilst also addressing infrastructure backlogs (DPLG, 2006). The adequate maintenance of road infrastructure in municipalities is crucial, as maintenance prolongs the lifespan and delays reconstruction. Adequate maintenance will also allow government to spend a significate less amount as opposed to 100% on infrastructure reconstruction if there is no maintenance on a projects with a design life of ten years, this means in year seven the road will require total reconstruction (R. McCutcheon, 1989). When performance is not reported and measured, that will make it difficult to measure efficiency of the road maintenance teams in municipalities.

The City of Johannesburg (CoJ) roads are managed by the Johannesburg Roads Agency (JRA). The other seven out of the eight metros do not have agencies managing their road infrastructure, but rather a roads unit are part of the internal metro structure. The other seven metros' performance results and key performance indicators (KPis) are different from the JRA. In order to measure operational improvement and efficiency of the maintenance teams, the performance targets should be in terms of response time. The analysis of the metros' roads infrastructure performance targets indicates that the Johannesburg Metro is the only one that measures response time. However, asset management systems information is not often efficiently used in decisional process in most municipalities, which results in much waste in infrastructure maintenance time and effort (D. Michele & L Daniela, 2010).

Even though the JRA seems to measure performance better than other metros, there is no evidence of a scientific study performed by JRA or CoJ in generating KPis. The monitoring of services in municipalities requires the achievement of realistic goals (D. Prestorius & W. Schurink, 2007). There is also no evidence of a study done around the capacity of the JRA operational teams in responding to service requests prescribed in the JRA Service Level Agreement.

2. Methodology

The method to be utilized in the research is the qualitative one with a number of interview, on-site motion study and
checklists. To ensure validity and reliability, a structured questionnaire will be utilized for the participants to answer.
The on-site study will be done in order to record activities "as is", this motion study will also ensure reliability of information. The questionnaire will include some of the following questions:

- Are there specific teams for reactive and proactive maintenance?
- How many teams are responsible for proactive maintenance of potholes?
- How many teams are responsible for reactive maintenance of potholes?
- Are all the teams trained to repair potholes?
- Are all the required resources available for pothole repairs?
- How many service requests are received daily?
- How many service requests are related to pothole?
- Is there a system that records all service requests?
- What other means are utilized to record service requests?
- How many service requests are attended daily?
- How many repeat service requests related to potholes?
- How many pothole repairs are attended daily?
- How many pothole repairs completed daily?
- Was feedback provided to all reported service requests?

The data that will be collected in the motion study will include:

- Arrival of teams at workplace
- Any toolbox talks before leaving workplace for site
- Time teams leave workplace for site
- Arrival on site
- Number of teams per task
- Extent of task
- Commencement and completion of the task
- Resourced utilised to complete a task

The following personnel will be interviewed:

- Municipal management (Head of Department, Depot Managers)
- Foremen
- Employees (Pothole repair workers)

The research will focus on JRA under CoJ and eThekwini metros. The two metros have seven (7) depots each and the plan is to focus on two (2) depots per metro as the activities are similar to the rest of the depots. The two depots that will be selected will be the ones with a higher rate of unattended service requests.

The following are some of the limitation of the study:
- Key personnel to be interviewed not available
- Data maybe be not available for assessment
- Municipalities may see the study as an intrusion of their space

3. Results and Discussion

The results from this study will address following:

3.1Maintenance planning and scheduling

Investigating the utilisation of municipal internal capacity versus external service providers will include maintenance planning and scheduling of work by internal teams. The JRA diagnostic review revealed that currently reactive maintenance disrupts scheduled maintenance operations. The study will therefore find the root cause of the challenge and further propose ways of balancing planned versus reactive maintenance in these metros. This will be done as follows:
- Investigating ways to enable certain teams to do reactive maintenance and others to do proactive maintenance.
- Investigating ways to implement an appropriate ratio of reactive versus proactive maintenance teams across the two metros.
- Analysing the metros existing routine maintenance plans and investigating ways of improving them taking into consideration the existing resources.
- The study will also investigate ways for the metros to determine a more effective method of allocating resources between maintenance teams.

3.2 Relationship between Fleet and Plant and maintenance depots

Investigating the utilisation of maintenance equipment and plants within the depots, studies have shown that some of the factors affecting the performance of the in-house maintenance teams include a shortage of spare parts for minor plants and equipment. In addition, plants sometimes have to wait for imported parts for yellow plants such as graders, resulting in a plant standing idle for a long period. In order to improve the working relationship between the Fleet and Plant depot and the maintenance depots, the study will investigate the following:
- A Fleet and Plant needs plan
- A Fleet and Plant efficiency mechanism for effective utilisation of plant and equipment by maintenance depots

3.3 Motion study

When investigating the response time in attending to road infrastructure maintenance service requests, there is no evidence of a scientific study performed by any of the metros in measuring the time taken in attending to service requests. There is also no evidence of the study done around the capacity of the operational teams in responding to service requests.
As part of the study, the following will be addressed:
- Identifying or measuring and documenting average time in attending to service requests to identify current performance levels per operation team.
- Developing individual or team performance targets for maintenance activities based on the improved work processes.
- Documenting the improved work processes for the various work activities and their related standard resource requirements.

- Developing maintenance framework for roads.
- Identifying on-the-job training requirements for foremen, supervisors and managers on the implementation of the improved work processes.

3.4 Training and development

Investigating the need for training and development of internal maintenance teams, studies revealed that maintenance activities associated with surfaced roads are more than those of gravel roads and these activities are more labour intensive. Irvin (1975) states that the number of general workers in the government has decreased due to poor management of the staff replacement and recruitment processes. In addition, management does not timeously request placements as people leave the organisations. There has been no training and development for new and existing employed staff in more than 5 years at JRA, which might be the cause of JRA not meeting its service delivery standards (GTAC, 2016). The study will focus on the following:

- Investigating the implementation of recruitment plan
- Recommending the necessary required training and development for all maintenance teams
- Investigating the need to have an in-house training and development centre

4. Conclusion

The research into the South African metros reveals that most of them are struggling to meet their service delivery targets relating to in-house maintenance due to e.g. (a) Underfunding for roads resurfacing and maintenance; (b) Inappropriate skills of some depot managers, (c) Longer time taken in attending to service requests; and (d) High vacancy rate.
The key focus will be on the basics of operations management such as planning routine maintenance activities, measuring the process and the areas affecting production, and analysing all the work components related to roads maintenance (e.g pothole repairs), which will lead to cost-effective maintenance implementation. The outcomes of this study should lead to recommending the increase in metro in-house employment, training and development of in-house personnel, reducing the outsourcing of maintenance services and operational improvement and efficiency of in-house teams.
Holzer and Seok-Hwan (2004) indicate that productivity is a function of many factors, including the following:

- Top management support
- Committed personnel at all levels
- A performance measurement system
- Employee training
- Reward structures
- Community involvement and feedback for the correction of budget-management decisions

Linna et al. (2010) also reiterate that a productive society is dependent upon a high-performing government. The intention is to ensure that improved productivity and efficiency in the road maintenance is supported by all parties involve, from the top management to the general workers.

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SCHEDULING REPETITIVE CONSTRUCTION PROCESSES USING A SWARM ALGORITHM

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Abstract

This article presents a method for multi-criteria optimization of repetitive construction processes schedules. Considering the limitations in planning the realization of such projects using classical tools and methods, the use of swarm algorithm for finding non-dominated solutions to the problem was proposed. An example of the application of the particle swarm optimization algorithm to the development of a schedule for the repetitive construction processes realization and the selection of work crews in order to minimize the realization time of the project and downtime in the work crews was also presented.

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Keywords: construction project management, construction scheduling, metaheuristic algorithm, particle swarm optimization, repetitive project scheduling.

1. Introduction

The realization of construction projects often includes the execution of a number of repetitive processes on the objects of a given construction project or their parts, referred to as working units. In literature, this type of projects are described as repetitive [1]–[3]. Due to the specific nature of the realization conditions, the classical planning methods (critical path method, PD method or PERT) are not adapted to support the management of this type of projects [4]–[6]. Therefore, a number of methods have been developed dedicated to the design of repetitive construction projects realization, such as LSM (Linear Scheduling Method) [7], RSM (Repetitive Scheduling Method) [8] or TACT and e-TACT methods [9]. One of the more popular approaches to support the management of repetitive construction projects when seeking multi-criteria optimization is mathematical modelling of construction management's preferences regarding optimization goals, taking into account the imposed realization constraints, and then solving the developed model using exact or heuristic (usually of high computational complexity), or meta-heuristic methods – in the case of complex scheduling problems occurring in practice. Meta-heuristic algorithms provide a general scheme for solving an optimization problem, based on processes occurring in nature, e.g. adaptation in the evolution process. An example of meta-heuristic algorithms, often used to solve scheduling problems, especially in industry, are swarm algorithms, for which an attempt was made in this paper to apply them to solve the problem under study.

2. Literature review

2.1. Meta-heuristic swarm algorithms

Optimization of schedules for repetitive construction projects is a difficult and complex process due to the following problems [10]–[12]:

- the number of possible solutions in the search area is so large that it makes it impossible or meaningless to use a comprehensive search to find the best solution,
- the model of the problem usually includes many constraints, which makes it difficult to generate even one acceptable solution, let alone find the optimal solution,

- the problem is so complex that in order to obtain a solution with a reasonable amount of computational time, it is necessary to use problem models so simplified that any solution is practically worthless,
- the value of the criterion function is affected by many decision variables, therefore it is necessary to review many solutions acceptable for various combinations of their values,
- the person solving the problem usually does not have the appropriate knowledge and skills in solving complex mathematical models.

Due to the aforementioned difficulties in finding solutions to the problem of scheduling repetitive construction projects, more and more perfect algorithms are constantly being sought to find an approximate, but still useful solution. One of the most popular approaches to finding suboptimal solutions to real problems is the use of meta-heuristics algorithms. Many of them are inspired by phenomena occurring in nature – the observation of behavior occurring in nature makes it possible to transfer existing phenomena to algorithmic procedures [13]. Among the numerous methods belonging to this group, the following can be mentioned:

- evolutionary algorithms, including genetic ones, based on the mechanisms of natural evolution,
- quantum genetic algorithms using the laws of quantum physics,
- artificial immune systems based on processes occurring in the immune system,
- artificial neural networks, imitating the processes in the human brain,
- simulated annealing algorithms resembling the annealing phenomenon known from metallurgy,
- herd algorithms, also called swarm algorithms, which derive from the so-called swarm intelligence of social organisms living in colonies.

Swarm algorithms have become increasingly popular in recent years. One of the reasons for this is their very large variety and the ability to adapt to the problem under consideration. Organism communities are a decentralized system composed of autonomous individuals, which can be described by certain probabilistic behavior – reactions to stimuli. The basic rules of their behavior are the result of local interactions and guarantee the spread of information within the colony and affect the attitudes of each individual. In herd behavior, coordination within a group of individuals corresponds with the organization of tasks required to solve a particular problem, while proper communication helps to make the best choice by exchanging information between individuals [13]. Table 1 summarizes the types of organisms and the type of herd behavior on which optimization in previously developed swarm algorithms is based.

The general scheme of the swarming algorithm can be written as follows [13]:

- coding and initialization of the initial population of solutions and evaluation of their quality,
- until the stopping criteria of the algorithm are met, cyclically repeat the following steps:
  - identification of the vicinity of current individuals,
  - selection of individuals representing the best solutions from the vicinity,
  - acceptance or rejection of candidate solutions,
  - creating a new population of solutions,
- decoding the best solutions found.

Table 1. Types of herd organisms on whose behavior swarming algorithms are based (based on [14])

.

Organism	Type of herd behaviour
ants	foraging
particles	aggregating
bees	foraging
masses	gathering
wolves	preying
bats	echolocation
bacteria	growth
fish	aggregating
birds	mating
dolphins	clustering
monkeys	climbing
fruit fly	gathering
firefly	gathering
cockroaches	foraging
cuckoos	brooding
krill	herding
frogs	jumping

2.2. Repetitive construction projects

In the unusually rich literature on the subject, one can find various tools tailored to optimize construction schedules of repetitive projects. The most frequently used methods of optimizing the schedules of repetitive projects include exact methods of solving mathematical models in the form of linear [15]–[16] or dynamic programs [17], as well as heuristic and meta-heuristic methods, e.g. genetic algorithms [18]–[19] and other more advanced ones [20]–[21]. Approaches using fuzzy logic are also being developed [22]. Some works have developed methods for determining construction schedules under risk conditions using simulation [23].

Regardless of the method of solution or modelling, the problem of scheduling repetitive projects was formulated with the following objectives in mind: minimizing the total project realization time [24]–[25], ensuring that the project deadline is met [26], minimizing the total cost of the project [27], seeking a compromise between the time and cost of the project [28], maximizing work efficiency [29], schedule resilience and reliability [30], ensuring the continuity of resources (minimizing downtime) [4], [16], minimizing the cost of breaks in the crews work [19] a combination of these criteria [5], [31]–[32].

For example, Sroka et al. [33] presented a model for scheduling repetitive construction projects in order to support the selection of the appropriate method of their realization and optimize the general contractor's profit, taking into account the amount of direct and indirect costs, as well as contractual penalties and the cost of downtime of work crews and credit service costs. The model was solved using a hybrid algorithm using a simulated annealing algorithm and a genetic algorithm. The operation of the proposed model was presented on a calculation example, and the results obtained in the model are fully satisfactory.

In turn, Tran, Chou and Luong [34] developed a stochastic model minimizing the realization time of a repetitive construction project, taking into account the different priorities of process significance. A new fuzzy hybrid evolutionary approach, called the artificial bee colony approach, was used to solve the developed model. Experimental results indicate that the proposed method provides the shortest average project realization time and the smallest standard deviation in relation to the optimal solution among the model algorithms considered in the work.

The same authors developed a method of finding compromise schedules due to the time and cost of realization. In [21] an adaptive multi-criteria search algorithm for symbiotic algorithms was developed. Two case studies were analyzed to validate the scheduling method, as well as to demonstrate the possibility of using the new algorithm to generate solutions. The obtained results indicate that the proposed algorithm is more effective in comparison with the basic search algorithm for symbiotic organisms and others analysed in this work.

The model developed by Wang et al. [35] makes it possible to search for a compromise between the time, cost and quality of repetitive construction projects. The authors used the NGSA (Non-Dominated Sorting Genetic Algorithm) to find non-dominated solutions to the developed problem model. An undoubted advantage of their approach is the quantitative consideration of the quality of the realized works.

The genetic algorithm was also used by Altuwaim and El-Rayes [19] to simultaneously minimize the duration of a repetitive construction project, the downtime of work crews and the cost of these interruptions. The algorithm for solving this problem includes four modules: optimisation, initial scheduling, intermediate scheduling and determining the cost of downtime for crews.

3. USING THE SWARM ALGORITHM FOR SCHEDULING REPETITIVE CONSTRUCTION PROCESSES – EXAMPLE

New methods of scheduling repetitive construction projects have been developed very dynamically in the last decade based on increasingly modern and advanced techniques. Nevertheless, it is very difficult to find in the literature examples of the use of swarm algorithms for scheduling the realization of repetitive construction projects. These algorithms are an extremely flexible and effective tool for finding suboptimal solutions to even very complex computational problems. Therefore, in this publication one of the swarm algorithms (particle swarm optimization algorithm) was used to determine the schedule of an exemplary construction project. The block diagram of this algorithm is shown in Figure 1.

The analyzed project consists of seven real processes and two fictitious ones: the beginning and the end of the project. The project includes the realization of three identical working buildings, being separate working units. The same processes are performed on each of them. Sequence relationships between processes within one working unit are shown in Figure 2. Two crews are available: crew B1 and crew B2. They can be assigned to realize different processes. The realization times of individual processes are shown in Figure 2 (the realization times of processes on individual work plots are the same). Due to the use of the learning effect, the crew assigned to realize a particular process will realize it on all work plots.

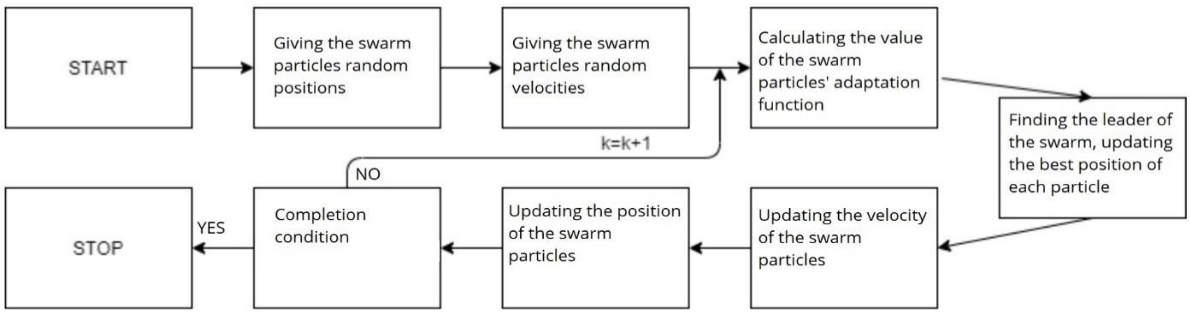

Fig. 1. Block diagram of the particle swarm optimization algorithm (based on [36])

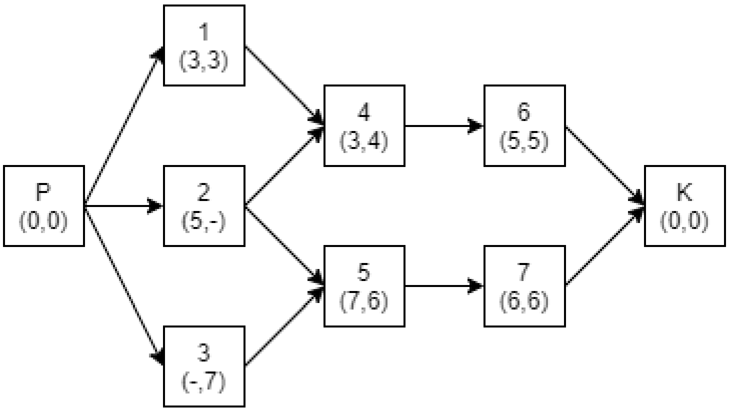

Fig. 2. Network model of processes realized on one working unit of an exemplary construction project (times of realization of individual project processes by crews B1 and B2, expressed in working days, are given in brackets)

As an example, the project realization schedule was simultaneously optimized in terms of three criteria:

- minimizing the realization time of the project
- minimizing the downtime of working crews,
- minimizing the realization time of construction facilities, remaining in relationship with the reduction of downtime on work fronts assuming that they are equivalent.

The example was solved using a particle swarm optimization algorithm. The calculation time was 46.53 seconds. The resulting schedule is shown in Figure 3 in the form of a beam graph. Crews B1 and B2 work without breaks, the realization time of the entire project was 57 working days, and the realization of each building object averaged 46 working days.

The developed algorithm can also be used for scheduling the realization of processes repeated on heterogeneous units, finding the optimal order of plot realization. Extensive examples of its use are presented in [37].

4. Summary

The article presents a method of scheduling repetitive construction projects using one of the swarm algorithms – the particle swarm optimization algorithm. The method presented in the article makes it possible to obtain compromise solutions due to three optimization criteria: minimizing the realization time of construction objects (work units) and the entire project, and minimizing the downtime of crews work. The obtained results indicate that the use of swarm algorithms for scheduling repetitive construction projects generates very good results and can support construction managers in finding solutions to this complex problem.

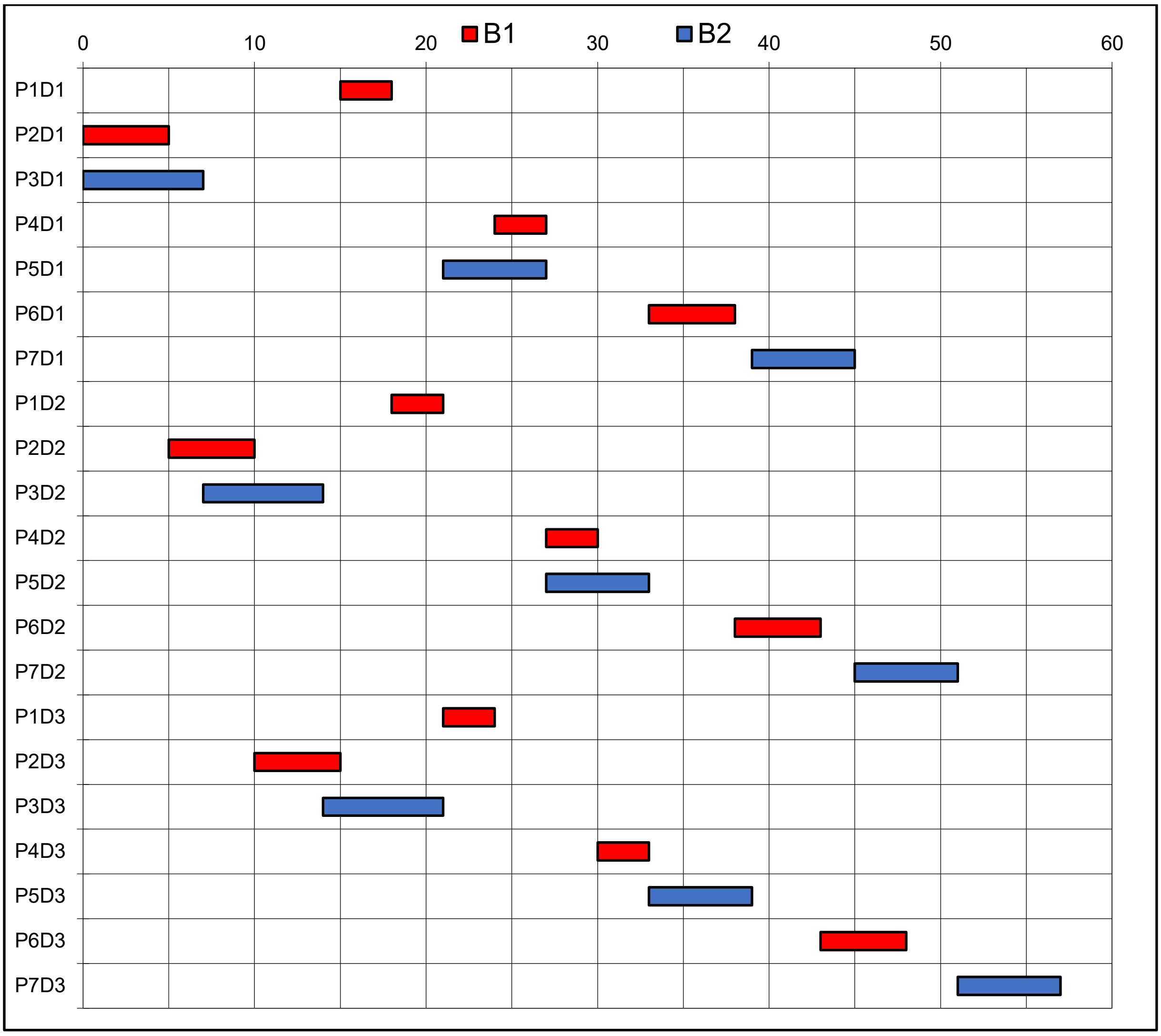

Fig. 3. Beam project realization schedule (solution for equal weights of optimization criteria)

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