Network-based Simulation in Water Construction – a Flexible Tool for Equipment Selection

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Abstract. A simulation model for the operation of barges and dredging platforms using AnyLogic was developed, allowing for optimization of equipment selection and cost calculation. The model is a discrete event model set up using AnyLogic's Enterprise Library. With a Monte-Carlo-approach applying the model, risks in cost and time planning can be quantified. Linking a generic version of the AnyLogic model with Excel and GoogleEarth, models for arbitrary water construction sites can be created and used by cost estimators without simulation modelling know how.

Introduction

Simulation is currently not very widely used in the construction industry. Reasons may, on the one hand, lie in the industry itself, which tends to be rather conservative. On the other hand, many projects have unique features and construction site layouts change with the progress of construction itself (imagine an assembly line that changes after every finished product), two factors which make the creation of simulation models difficult. Another challenge is the traditional way of developing a construction project, where final designs and construction methods for certain parts are only available after the start of construction.

At STRABAG's Central Technical Department in Vienna, a group of experts on mathematical modelling and simulation develops models for applications in the whole range of construction projects to secure the company's position as innovation leader in the construction industry.

It could be shown that simulation is a suitable instrument to examine the influence of certain phenomena on dredging, which is the process of earthworks under water. These phenomena, such as bad weather, technical defects, interruptions of supply, etc. on a dredging project, are outside the sphere of influence of the construction contractor, are mostly of a stochastic nature and can often have a significant impact on the cost of the relevant construction activity. Simulation supports in quantifying the influence of these factors and can therefore help reduce price risk for the construction contractor and its client. Some of the difficulties mentioned above are not present in this special kind of construction operation.

In the following, we present a flexible framework to dynamically generate simulation models of arbitrary harbour dredging projects with variable equipment fleets.

Figure 1: A dredging platform with a bucket excavator, bucket size 14m³.

1 Problem Formulation

In many harbors it is necessary to remove silt from basins and channels as part of the maintenance works or to increase the accessibility for larger ships.

Usually these works are carried out with dredging platforms (platforms which are fixed to the seafloor with stilts in the area of operation with a bucket excavator mounted on top, see Figure 1) and a fleet of barges which transport the material from the dredgers to spoil areas at some distance from the harbor entrance.

In addition to the dredgers and barges, tugs are needed to manoeuver the barges in the vicinity of the dredgers and to tow barges of the non-automobile type to the spoil areas and back to the dredgers. Modern tugs with enhanced maneuverability are used for moving the barges in the vicinity of the dredging platforms. Simpler and more inexpensive tugs are used to tow the barges to the spoil areas and back. Usually there are several dredgers, several dredging and spoil locations and a variety of barges and tugs involved in this kind of construction activity, see Figure 2.

Figure 2: Dredger in operation with two barges and a tug. The landing manoeuvre of the barges requires experienced captains in order to keep the disruption of digger usage short.

The equipment cost is essentially time based. However, a merely performance based approach does not lead to reliable results due to presence of phenomena influencing the construction process that are often interlinked and clearly outside the sphere of influence of the construction firm. These phenomena include but are not limited to: Unsuitable weather conditions, damage of barges or other equipment, necessary refuelling of the excavators, the passage of large ships, unsuccessful landing of barges, and the relocation of dredging platforms. All these items lead to a disruption of the construction process, reducing the degree of utilization of the dredgers, hence increasing total construction cost. The key to minimizing costs is maximizing the degree of capacity utilization of the dredgers as the most costly elements which is done by ensuring a continuous servicing of dredgers with barges.

Finding the right fleet composition for the barges is vital for achieving cost efficiency, especially because changing the fleet is very costly and time consuming. A sound simulation model enables the cost estimator to work with scenarios in order to find an 'optimal' fleet composition before the works start.

Compared to earthworks on land (as in conventional road construction), which can be optimized using linear programs (Bogenberger et al., 2013), the costs are higher and less units (barges, dredgers) are in use.

In order to create a more solid basis for cost calculation a framework for automatic simulation model creation was developed. The resulting model enables the user to carry out Monte-Carlo-analysis as well to further secure cost calculation results.

2 The Model

The nature of the problem described above suggests using discrete event simulation in order to quantify the bandwidth of the influence of the disruptions on the duration of a given construction project described before.

In summer 2013 a subsidiary of STRABAG was carrying out a dredging project in the harbour of Yuzhne, Ukraine.

Thus, activity reports of 3 dredging platforms for almost one year were available, making it possible to determine the probability distributions for the disrupting phenomena of interest. Data analysis, using R, has shown that a lognormal distribution is a suitable model for all these phenomena.

The simulation model was created using the simulation software AnyLogic (6.8.1), which had proven to be suitable for modelling construction related processes before in STRABAG's Central Technical Department (e.g. for tunnel construction, material supply in tunnel construction, material flow in a quarry, influence of construction activities on traffic, etc.).

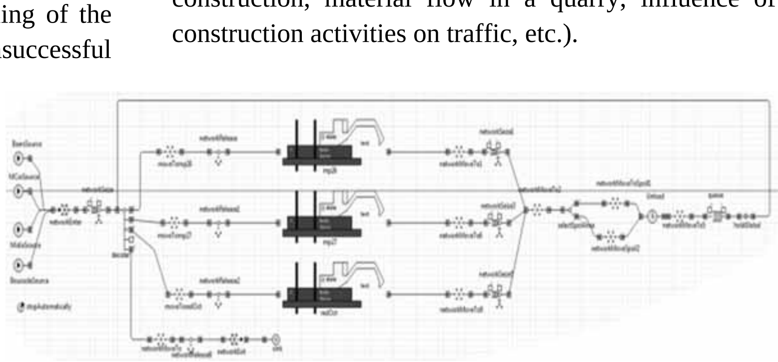

Figure 3: Modelling view in AnyLogic, showing the use of the Enterprise Library Network Blocks.

For the model presented in this paper a network based modelling approach was used, applying elements of AnyLogic's Enterprise Library, see Figure 3. Herein the locations, such as dredging and spoil sites and anchorage are the nodes and the routes along which the ships move are the vertices.

The network geometry is taken from a map of the relevant area. In the first phase of the research the network was literally drawn on a sea map of Yuzhne as can be seen in Figure 4.

Barges are entities that populate the network. The tugs are modelled as network resources, which means that the barges request the tugs in accordance with the task that has to be carried out and the network object itself provides the entities with the requested resource as soon as it is available.

The dredging platforms are modelled as Active Objects, located at certain nodes in the network. They consist of a workflow for incoming barges, modelled with objects of the Enterprise library and state charts, controlling the different modes of operation a dredger has, in detail a state of regular operation and all disrupting states as failures and disturbances.

A close to optimum disposition of the barges to the dredgers is crucial to minimize idleness of the excavators. Therefore, on site a human dispatcher controls the operation of the barges.

Figure 4: Map of the example region in Yuzhne, with the network used by the Enterprise Library Network blocks.

In the model, the dispatcher is represented by the 'Disponent' object, which iterates over all operational dredgers once a barge is unloaded at a spoil area and identifies the dredger with the least shipping space on the way and then sends the relevant barge to its dredging area. As in reality, the 'Disponent' object is called each time a barge has completed a task and a new destination for the respective barge has to be determined.

The events in the simulation are triggered by a random number generator using the frequency distributions and durations calculated from the reports of the dredgers. Parameters were calibrated using site data.

The validated model was then used to try a variety of different sets of equipment for the given project in order to find an optimal equipment configuration.

3 Validation

Similar to the real system the dredging platforms in the simulation model can create activity reports. This data was used to validate the model. The data of 30 days in the real system were compared to 30 simulated days. Simulation results match the real world results satisfactorily (see Table 1). Observing a longer timespan obviously leads to a better agreement with real world results.

	count		mean duration	
	real	sim	real	sim
loading	493	543	79,30	77,35
position change	57	38	56,43	58,32
repair	56	33	226,55	113,91
ship traffic	52	33	87,45	115,89
barge shortage	188	212	70,05	136,11
refueling	19	13	64,44	65,12
bad weather	27	39	416,35	661,14

Table 1: Comparison of a single simulation run with measured data.

4 Generalization

In order to allow application of the model to other construction sites of the discussed type, dependency of expert model developers had to be reduced. A tool had to be created which allows estimators without knowledge of modelling software to adapt the model to their respective construction project. Acceptance of this tool by estimators and simplicity of usage is crucial for introduction of simulation as a method for cost estimation and risk management.

In order to achieve this goal, object replication and connectivity features of AnyLogic were used. In a generic model, location of dredging sites, spoil areas, and ship routes are input via kml-files which are produced using GoogleEarth. Additional information on barges and dredgers are input via Microsoft Excel into standardized forms, which are partly created dynamically via VBA.

The Anylogic model reads the kml- and the Excel-file and sets up the model accordingly.

Training of estimators and application to new construction sites is part of an ongoing development project.

5 Monte Carlo Analysis

Recent dredging projects calculated without application of detailed models showed that the inherent risks of such a project were not accounted for sufficiently. The results were economically unsatisfying. It is assumed that normal operation could be quantified well using traditional ways of calculation with mean operation times. Risk factors added to the calculated costs are gained through experience. Of course, setting these factors is crucial, if they are to low, costs cannot be covered, in the other case, the projects are not won in the first place.

The calculated actual costs should nearly be the same for comparable companies. They use similar equipment, pay similar wages to workers and have similar management structures.

The ability to quantify of risks can therefore be the differentiating factor between the loosing and the successful bider.

In the model presented above, various stochastic elemts are present. Unfortunate combinations of their expressions can lead to significantly higher construction times (and therefore costs). Starting with a few hundred model runs of a Monte Carlo Analysis, the histogram of construction costs typically converges to a smooth curve, defining the distribution of the resulting construction costs. An example is depicted in Figure 5. Using this knowledge, the cost estimator can price for risk consciously, replicably, and in a project specific way.

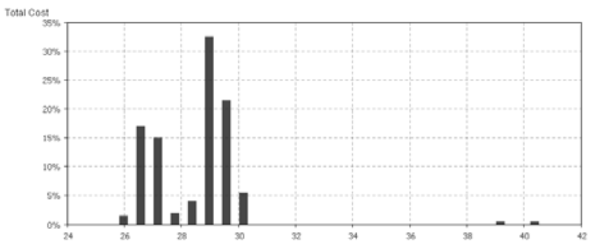

Figure 5: Histogram of simulation results (costs in Mio. €) from a Monte Carlo run with 200 iterations. The outliers can be explained by an unusual accumulation of condounders.

6 Conclusions

Simulation of logistic processes is currently not very widely used in the construction industry (an overview of existing approaches can be found in Günthner et al., 2012), despite the fact that many of its processes are predestined for simulation due to the circumstance that construction processes are very often so costly that real experiments cannot reasonably be carried out and external influences, which are hardly quantifiable, have an important impact on construction processes.

Yet it could be shown that simulation can be put to use for cost calculation and risk estimation, generating a significant benefit for the user. This project shows that highly flexible tools can be created in a way that estimators unfamiliar with modelling and simulation can use them.

Through application of simulation models in certain niches the degree of familiarity with and the trust in these instruments can certainly be increased. If we succeed in reproducing the complexity of large scale construction activities with semi- or fully automatized generated models, maybe also in connection with improved data models, it will be possible to facilitate a number of decisions with simulation models that can be generated quickly and inexpensively. Of course, in the future the majority of construction projects will still be satisfactorily planned and executed by experienced project managers. But more and more complex projects are harder and harder fully to perceive by a single human being. Therefore, prospects for simulation models in the construction industry are increasing and therewith the prospects for the players in the construction industry using the instrument of simulation. (Höfinger, 2014)

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