SIMULATION IN LARGE-SCALE PRECAST OPERATIONS

Edmundo Balbontín-Bravo

Dragados. Planificación y Métodos
Avenida de Tenerife 4 – 6
28700 San Sebastián de los Reyes (Madrid). SPAIN.

ABSTRACT

This document details a rationalisation study on the production of shop-prefabricated parts supported by simulation to analyse potential operating alternatives. The goal was quite specific: to improve productivity and so reduce production costs.

Since the study was carried out while the workshop was fully operational, no changes that would have involved stoppages in workshop production could be considered.

An initial model was designed reproducing the established method, with a production rate of 75 parts per shift. The results obtained were in good agreement with the real-life situation. Alternatives were analysed by making gradual changes to the initial model: assigning jobs to the workforce, homogenising the number of parts being processed during each of the successive stages, and altering working hours.

The simulated production of the final model tested was 108 parts per shift, i.e. an increase in productivity of 44%. When this solution was implemented the model was shown to have been accurate, with the forecast production being achieved within only a few days with absolute regularity.

Before the case is described, an overview of the path followed by Dragados in the process of adopting simulation as a tool for enhancing productivity is given.

1 SIMULATION AT DRAGADOS

Dragados is a group of over 50 companies, the result of an intensive process of diversifying the main activity, construction. With annual sales of over 550,000,000,000,000 pesetas, Dragados carries out a major part of its activities abroad. In the August 1996 issue of the Engineering News Record issue on the Top 225 International Firms, Dragados was ranked number 54 as an International Contractor (included only contracts outside of their home country), number 37 as a Global Contractor (home and abroad) and number 8 as a Latin American Contractor.

Throughout its history, Dragados has considered it vital to have a strong team of highly qualified technicians with solid know-how of the latest technologies and their operational application. This philosophy led to the formation of technical teams specialised in each area of the company's activities: in other words, specialisation by products.

In parallel, the technical-development process was implemented in all departments, with production-line support groups being set up using generalist techniques.

In the late 60s the Planning and Methods Unit (PMU) was created, with a view to enhancing the productivity of construction processes by the application of work-rationalisation techniques.

Processes are designed by the product specialists. The generalist detects opportunities for improvement, using Work Study techniques to analyse and summarise the processes and handling highly detailed information:

- Breakdowns of item cycles, measured in hundredths of a minute..
- Existing conditions between operations, not just in order. Also by the cyclical use of space.
- Often, the summary is made on a Multiple Activity Chart, which basically amounts to a graphic simulation done by hand.

When simulation software applicable to construction operations first became available in the early 1980s, the PMU recognised its potential as a tool for standard work processes and so began to implement computerised techniques.

We may conclude that simulation was implemented to meet the operational needs of a pre-existing operational group with the basic mission of increasing productivity: the function exists; the tool is useful.

The PMU performed tests on the available software, devising models of different construction processes, and decided to adopt the Microcyclone PC version of the MCYCLONE methodology.

It was felt that any model must comply with two key conditions. First, it must provide an accurate reproduction of reality. This was achieved, to differing degrees of success, by all the software tested. It boils down how costly the specialist's learning is going to be.

The second condition resulted from liaison between the PMU and the production staff: any proposed changes must be solid and understood by the client. It is not possible for the production line to specialise in designing models: we believe it it be sufficient for the line to understand, with few explanations, how any given model designed by the specialist works.

This second condition is what led Dragados to opt for Microcyclone. The low number of items used in its models makes them readily comprehensible for works personnel.

The Microcyclone software, which is constantly being upgraded thanks to the tireless efforts of Prof. Daniel W. Halpin, was enthusiastically received by the PMU team. The cordial relationship between both parties enabled Dragados to develop a version called Prosidyc, which includes certain enhancements that are of particular interest for the PMU. These are the ones that I recall:

- New interactive input model, with key-by-key control, to ensure the quality of the information entered.
- Multiple arcs, originating in a QUEU. The relationship between two nodes can be defined as multiple, such as M6. This means that six flow units are needed in the queue in order to be able to process the corresponding COMBI operation. Particularly useful for putting together differently sized teams for different operations from a single queue.
- Multiple arcs originating in a NOT QUEU node. In this case, M6 means that a flow unit is processed in the arc, delivering 6 flow units to the next one. It works as a GEN QUEU, with no need to include a queue in o the model.
- Double-arrow queues. An arc with an arrowhead at each end represents a dual relationship: the two related nodes are source and target. The only purpose of this is to simplify the plotting of the model.
- Resource reporting module, facilitating information on the production saturation and capacity of each. By indicating bottlenecks, the most useful direction of change is suggested.
- Multiple Activity Chart. This report is the most appropriate for the implementation of new working methods, since it clearly explains in detail the organisation of the job. The entire management chain understands it.

The PMU uses Prosidyc frequently for construction processes of all kinds: tunnels, maritime works, dams, roads, etc.

The case presented below was developed in a prefabrication plant. However, this does not imply that fixed facilities are the most suitable venue for the use of such techniques. On the contrary, this case has been selected precisely because of the greater difficulties involved in obtaining excellent results in fixed work centres, where processes are more highly perfected than those used for *ad hoc* jobs.

2 PREFABRICATION WORKSHOP

For the execution of a sewer with an length of 6,353 m, most of which was underground, a tunnel 5,850-metres long was excavated with a 3.25-m-diameter Earth Pressure Balance (EPB) excavating machine. The lining, made of prefabricated concrete, shapes the sewer. The cycle of the EPB machine consisted of two phases: an advance in excavation of 1.2 m and the fitting of a ring of the same length, composed of 6 precast segments (PS).

The prefabrication of these parts was the object of the present study. The production schedule was 4,875 rings, i.e. 29,250 PS. When the study was carried out, 88% of this total (25,600 PS) still remained to be produced.

In the description of the situations observed and proposals made, details that draw attention away from the key aspects of the systematics of the improvement process have been excluded..

2.1 Situation observed

A daily production rate of 150 PS was achieved with the following working hours:

Day shift

From 7:00 a.m. to 7.00 p.m., with a break from 9:00 a.m. to 9:20 a.m. and another from 1:00 p.m. to 2:10 p.m.

Night shift

From 7:00 p.m. to 7:00 a.m., with breaks from 10:00 p.m. to 11:10 p.m. and from 4:30 a.m. to 4:50 a.m.

The total working hours were therefore 21 hours out of 24.

Description of process

For the parts model vibrating benches were used with 4 side closings and 2 top lids. The dimensional tolerances were very strict, leading to extremely high formwork costs.

Steam-curing enabled several pourings a day to be obtained. There were 54 benches. For the production of 150 PS, an output of 2.78 PS per day per mould was being obtained.

This is equivalent to a practical formwork cycle of 8.64 hours (518 minutes).

Since all operations in the workshop revolve around the moulds, by tracking their progress we can follow the entire process.

Once the cycle of steam-curing the part is complete, the following operations occur:

Stripping Phase 1

A team of 4 workmen removes the canvas covering 2 PS during curing, lifts the top lids and removes the closings from the mould and the hollow negatives.

Lifting parts

An overhead crane removes the part from the mould and transports it to the end of the workshop, where it fitted with other parts until a ring is formed.

Stripping Phase 2

The same team as in Phase 1 cleans the formwork and applies releasing agent and paraffin.

Forming

A team of 4 workmen fits the closings and lids and places reinforcement partitions.

Reinforcement-cage supply

A team of 2 workmen and a cart supply the reinforcement for 12 PS on each trip.

Concrete pouring

A gantry crane and a crew of two workmen pour concrete for lots of 6 PS each with 2 dumps per lot. There are therefore 12 dumps per lot.

Finishing

A crew of 4 finishes the surface of the concrete-pouring window.

Canvas covering

The reinforcement-cage supply team covers 2 PS with a sheet of canvas.

Temperature control

1 workman is responsible for controlling the curing heat cycle.

The part continues through its cycle until the lifting operation detailed above, finishing with the formation of a ring. The process then goes through the following stages:

Transport to stockpile

Carried out by a fork-lift and 2 workmen.

Repairs

Any defects are repaired by 2 workmen, who also water the parts frequently during the first day.

Final check

The crew foreman marks the ID data for the PS: Type, date and manufacture number.

The full crew for each shift is composed of 24 men, 54 moulds, 1 overhead crane, 1 gantry crane, 1 fork-lift and 27 canvas sheets.

2.1.2. Time study

As a preliminary step before any analysis is carried out, reliable, detailed information must be obtained on the duration of each stage and the resources used. The tools used for this are Time Study, applied to measuring the machine cycle, and Work Sampling, for measuring work performed by human resources.

The times measured for each stage of the process described are listed below. In order to avoid a mind-numbing avalanche of information, the study is presented in some detail for only the initial stages of the process, followed by a summary of the results for the whole process.

Stripping Phase Crew 1 & 2: 4 workers.

There are 3 types of PS. The work has been measured for each of these 3 cases. The information corresponding to the most frequent PS type is:

Phase 1

Task	Worker ·minute/PS	%
Retrieve canvas	1.75	10.7
Loosen screws	3.65	22.3
Withdraw inserts	1.25	11.9
Retrieve woods	0.35	2.1
Open closings	6.90	42.1
Remove negatives	0.25	1.5
Lift lids	0.35	2.1
Total	16.40	100.0

Phase 2

Task	Worker·minute/PS	%
Clean forms	19.25	72.6
Air blow	1.25	4.7
Apply paraffin	6.00	22.7
Total	26.50	100.0

The work consumed for the two stages and 6 PS of a ring is 240 Mm (4 Man-hour/ring).

Lifting of parts : 1 overhead crane.

The overhead-crane cycle consists of the following times, for a transport distance of 58 m:

Task	OhC·minute/PS	%
Grab	1.05	18.8
Lift	0.20	3.6
Move	1.45	25.9
Drop	1.10	19.6
Return	1.45	25.9
Approach	0.35	6.2
Total	5.60	100.0

The cycle, in minutes, as a function of distance d is:

$$Ci = 2.7 + 0.05d \qquad 12\ m < d < 110\ m$$

Varying between a minimum of 3.30 min and a maximum of 8.20 min.

Summary of times measured

Stripping. 4 workers.

Work quantity 240 worker·min/ring.

Average time 60.0 min/ring.

Capacity 1.00 rings/hr.

Forming. 4 workers.

Work quantity	151 worker·min/ring.
Average time	38.0 min/ring.
Capacity	1.58 rings/hr.

Concrete-pouring. 2 workers + 1 gantry crane

Work quantity	43 worker·min/ring.
Average time	21.2 min/ring.
Capacity	2.80 rings/hr.

Finishing. 4 workers.

Work quantity	76 worker·min/ring.
Average time	19.0 min/ring.
Capacity	3.16 rings/hr.

Canvas, forms, spacers. 2 workers.

Work quantity	42 worker·min/ring.
Average time	21.0 min/ring.
Capacity	2.86 rings/hr.

PS transport. 2 workers + 1 overhead crane.

Work quantity	66 worker·min/ring.
Average time	33.0 min/ring.
Capacity	1.80 rings/hr.

Ring transport. 2 workers + 1 fork-lift.

Work quantity	24 worker·min/ring.
Average time	12.0 min/ring.
Capacity	5.00 rings/hr. .

Vibrating tables.

Work quantity	518 table·min/PS.
Average time	57.6 min/ring.
Capacity	1.04 rings/hr. (24 hr/day) 150 PS/day

2.1.1 Comments on times

According to the times measured, the bottleneck is the labour of the stripping crew, which enables a production rate of 1 ring/hr. With a 21 hr/day schedule, 21 rings/day would be obtained, i.e. 126 PS/day.

The sizes of the crews described was as stated in the established procedure. In practice, the foremen corrected the manning schedule by moving one workman from finishing to stripping, making the times of these operations as follows:

Stripping. 5 workers.

Work quantity	240 worker·min/ring.
Average time	48.0 min/ring.
Capacity	1.25 rings/hr.

Finishing. 3 workers.

Work quantity	76 worker·min/ring.
Average time	25.3 min/ring.
Capacity	2.37rings/hr.

This practical arrangement gives a production rate of 1.25 rings/hr, the equivalent of 26.25 rings/day and 157.5 PS/day. This production was slightly greater than that resulting from the vibrating-table cycle (150 PS/day).

A model was designed to simulate the process. First, the theoretical and practical sizing data was entered to validate the design.

This time data suggests changes that could be made in the following directions:

a) Balance the manning of the crews.
b) Improve the vibrating-table cycle, which consists of 300 minutes of curing and the time the time taken by the crews between removing the formwork and starting curing. It was observed that in order to prevent crews from interfering with one another, tables were left unused between successive stages. These gaps were eliminated from the alternatives devised.
c) With the same aim, the number of vibrating tables processed simultaneously in stage of the process was made equal.
d) Different working hours were simulated with a view to maintaining a cyclical work rate for each shift with the workers' breaks for steam-curing.

Changes were introduced in successive alternatives and largely as a result of the corresponding simulations.

2.2 Alternatives

Alternative 1. Production: 94 PS/shift

The lack of synchronisation between crews was eliminated, in such a way as to enable operations to be carried out as soon as they could. The manning of certain crews was also altered: 2 workers from finishing were moved over to stripping. The other crews were unchanged.

After the simulation it was observed that the formwork-removal, forming, PS-transport and finishing teams were saturated, while the concrete-pouring and canvas-placement crews were oversized

Alternative 2. Production: 96 PS/shift

One more worker was added to the workshop and the assignation of jobs was changed, as follows:

Stripping phases 1 & 2 + PS transport: 5 x 2 workers.

Forming and concrete-pouring: 3 x 2 workers.

Finishing and others: 2 x 2 workers.

Alternative 3. Production: 104 PS/shift

The crew composition from alternative 2 was kept. The formwork-removal time was brought forward by 30 minutes.

Alternative 4. Production: 105 PS/shift

As for alternative 3, except that the stripping team forms the first 3 moulds in each shift. The resulting improvement in production was not significant, so new ideas were tried out.

Alternative 5. Production: 105 PS/shift

The balance of the crews was achieved, including the condition that the same number of PS must be processed in each stage. It was decided to pour lots of 3 PS each, which meant that the same number of lots would be processed during formwork-removal and forming. The crews were manned as follows:

Stripping phase 1 + PS carrying: 3 x 2 workers.
Stripping phase 2 + Forming: 3 x 3 workers.
Concrete-pouring, finishing, others: 3 x 2 workers.

The start of stripping and forming was 30 minutes before concrete-pouring, thereby shortening the vibrating-table cycle. The simulation shows that the crews are left with no moulds during the hour before meal-breaks.

Alternative 6. Production: 108 PS/shift

Identical to alternative 5, except that meal-breaks were brought forward by 30 minutes. In this solution an exact repetition of the work of the two shifts is obtained: the 54 moulds are used twice in each shift, which means that each job finishes in the same state in which it started.

2.2.1 Summary of alternatives

The key details of the simulations carried out are summarised in the following table.

Alternative	PS/shift	N° workers	W-min/PS
Original Operation	64	18	179.4
Alternative 1	94	18	120.6
Alternative 2	96	18	131.2
Alternative 3	104	20	121.2
Alternative 4	105	20	123.8
Alternative 5	105	21	126.0
Alternative 6	108	21	120.5

Each of the alternatives is documented with the corresponding model and a Multiple Activity Chart for the crews, which because of its size cannot be included here. The chart for each solution takes up 14 pages of A4 paper, representing jobs with a duration of a few minutes throughout the 750-minute process, somewhat more than half a day.

2.3 Implementation

Alternative 6 was proposed to the workshop management at a meeting held on 9 September.

The presentation was set out as follows:

a) Explanation of the initial-situation model.
b) Comments on the results of the initial-situation model.
c) Successive alterations to the model, building in the changes proposed.
d) Comments on the problems detected when each change was simulated.
e) Presentation of the model corresponding to the alternative proposed.
f) Detailed analysis of the simulation reports for the proposal, particularly for the cycle obtained on the Multiple Activity Chart.

The information handled from the models and charts was easily understood by the management and mid-level managers.

Simulation proved to be a convincing factor. The meeting ended at 6 p.m. The management of the plant decided to start implementation with the shift that was due to start one hour after the meeting ended.

The production rates evolved as follows:

Date	Shift 1	Shift 2	Total day
Sept. 13	78	103	181
Sept. 14	91	108	199
Sept. 15	100	101	201
Sept. 16	99	86	185
Sept. 19	108	108	216
Sept. 20	108	108	216
Sept. 21	108	108	216
Sept. 22	108	102	210
Sept. 23	108	105	213
Sept. 26	108	108	216
Sept. 27	108	103	211
Sept. 28	108	108	216
Sept. 29	108	101	209
Sept. 30	108	108	216
Oct. 03	108	108	216

The production rate of 216 PS/day was achieved on the fifth day and maintained for 3 consecutive days. There was subsequently a slight loss of production due to negative changes in the speed of steel supplies.

3 OTHER STUDIES MADE BY DRAGADOS

A great many processes have now been analysed with the aid of Prosidyc/Microcyclone. Reference will be made to only a few cases of particular interest because of their application to certain specific objectives.

3.1 Sliding a floating caisson

For the construction of a quay large floating caissons (42.25 m long, 15.65 m wide and 16.5 m high) were made.

The shaft was poured by pumping, using two pumps (50 m3/hr each), located below a concrete plant. The plant prepared the concrete and discharged it into a hopper that fed the pumps.

When the support structures were moved under the sliding formwork, the pumps had to interrupt the concrete-pouring. The high frequency of these stoppages made it clear that it would best to reconsider the volume of the hopper so that manufacture and pumping could work independently.

Simulation enabled the exact volume to be determined, thereby achieving a significant increase in production (45%).

3.2 Concrete manufacture

A concrete plant was acquired from a manufacturer who claimed a production rate of 50 m3/hr for it. When it was first installed, the maximum production obtained was 33 m3/hr.

At the request of Dragados, the manufacturer sent a team of technicians to the site with the aim of improving production. Certain corrections were made, which, although they did improve the quality of the process, failed to solve the problem.

Simulation of the plant cycle revealed a possible improvement that would enable 43 m3/hr to be achieved. The manufacturer, impressed by the tool used, readily accepted the improvement.

3.3 Pouring of RCC dams

The reorganisation of work, lift by lift, needed for the pouring of a roller-compacted concrete (RCC) was designed very easily using a model for spreading, compacting, downstream forming and other necessary operations.

The dam plant was divided into the lanes that were to be spread and those in areas where they could be spread all at once. The jobs were related to these areas.

The result of the simulation—the Multiple Activity Chart obtained—is a detailed plan of the activities to be carried out in each area.

3.4 Track renovation

Railway tracks are being renovated, with the grade and entire infrastructure being changed. The works are being carried out with limited working hours (approximately 6 hours at night) when traffic is interrupted.

The intensive co-ordination required between the different resources involved in completing each night's stretch and open it to traffic, together with the obvious limitation in the space available, is a problem that could have been purpose-built for simulation, with no risk of a mistaken organisation of tasks being adopted.

Prudence prevents us from carrying out tests with a risk of failure. Consequently, short production goals are usually set.

Simulation has been applied to avoid these drawbacks, and the daily production achieved has proved to be twice that originally forecast. The improvements have been adopted in the following works.

3.5 Tunnel excavation by blasting

The excavation cycle of a tunnel always depends on the scarcest resource: working space. Operations at the face occur one after the other: setting out drafts, drilling the face and anchoring pinions, blasting, rubble removal, etc.

Improving an excavation cycle usually involves two approaches:

- Simultaneity of jobs at the face.
- Fluidity of communications with the exterior.

In both cases the idea is to make the best possible use of the space available: the space at the face in the first instance and the space between the face and the exterior in the second.

Simulation-based simultaneity analysis of the face and transport has enabled significant improvements (20%) in excavation cycles to be obtained.

3.6 General observations

We believe simulation to be especially useful for the analysis of processes demanding major co-ordination, generally because of conditions of limited space.

It is just as useful in cases that are just the contrary: the activities of the crews are not carried out with a compulsory sequence of tasks, but by defining priorities.

Most of the most useful models have consisted of queues and COMBI operations. NORMAL tasks are few and far between, indicating that there are many conditions or options. A large number of NORMAL tasks indicates that the modeller has taken order decisions. This may be forced, in which case simulation will not be particularly useful. If tasks are ordered potentially better possibilities are eliminated—and that is an error.