A Training Simulator for Cutter Suction Dredgers: Bridging the Gap between Theory and Practice

Abstract

The last decades have seen a major improvement in the knowledge of the dredging processes. Research and Development work from laboratory tests and field work resulted in improved mathematical models describing the behaviour of the cutter suction dredger. In this regard, some interesting process models have been developed for interaction between the soil and the cutterhead, behaviour of the dredger in waves and current, control of winches and the forces on anchors and spuds, and suction process, pumping and hydraulic transport of the mixture. This know-how has been used to improve the calculation rules for production estimates and for modifications of the dredger. Included in the modifications of the dredgers are improved instrumentation and automation systems. But knowledge of the R&D engineers in the headquarters of dredging companies is not easily transferred to the dredging site.

The main objective of the cutter suction dredger simulator is the transfer of expertise from headquarters to the dredging site. Instruction with the simulator emphasises the acquisition of advanced knowledge, understanding of new insights in the dredging processes, and application of the acquired skills in practice. Benefits are expected in an improvement of communication, control of the dredging processes, and most of all production.

During the development of the simulator project great emphasis was given to the educational aspects. First, educational goals were derived from a detailed task analysis of the dredging processes. Second, an instructional method was defined that provides a balance between simulator training and instruction on the theory of the dredging processes. Each training session on the simulator is embedded in a unique framework of briefing and debriefing with the instructor supported by instructional materials. The educational approach has resulted in a simulator training programme that bridges the gap between theory and practice.

This paper describes the benefits of the use of computer simulations in the training of dredge masters and the educational aspects relevant to the development of
Introduction

In the spring of 1995 Royal Boskalis Westminster nv completed the building of a training simulator for cutter suction dredgers. This full mission simulator, which is located in Papendrecht at the headquarters of Boskalis, consists of four rooms:

- two training rooms, containing a dredging installation with a desk monitored by one instructor station;
- an instructor’s room for briefing and debriefing; and
- an instruction room, where classroom activities take place.

During a training session the instructor monitors the activities of the dredge masters from the instructor’s room (Figure 1).

The training rooms are equipped with sound simulation and a presentation of the outdoor world, which is projected in front of the dredge master. All these factors contribute to the idea that the dredge master is located on the bridge of a genuine cutter suction dredger.

An extensive educational programme has been developed to run parallel with the development of the training simulator. This educational programme is tightly linked to the simulator containing both the assignments and the instructional materials necessary for well balanced training. Apart from this installation much effort has been put into creating a Computer Based Training programme, which is an interactive learning platform for individual students.

Educating Dredge Masters

The Traditional Way of Education

In the early years of dredging, knowledge of the dredging process was solely obtained by experience. Nowadays junior dredge masters are taught the basics of dredging at a dredging school. This knowledge, however, is purely theoretical. Later on, when the junior dredge master is working with a dredging company, their theoretical knowledge is enhanced by on-the-job experience (Figure 2).

From time to time the theoretical knowledge of dredge masters is updated during additional courses on dredging. This education, which is mostly held in classrooms, is sometimes organised by the company itself and sometimes by the Dutch Association of Dredging Contractors in The Netherlands. In both cases, however, there is always a threshold for the dredge master who is not used to classrooms and books.

Another way of updating the theoretical knowledge is by transferring it from experts from various staff divisions who are visiting dredging projects. In most cases these experts are not familiar with teaching. For this reason, the effect of this knowledge transfer is not always satisfactory. Practical experience can only be acquired by dredging in day-to-day dredging projects under a variety of circumstances. After joining one of the dredging companies, junior dredge masters will gain experience on board of a dredger itself, by working with dredging equipment. Although they will learn a great deal from the more experienced dredge masters, it will actually take many years before a junior dredge master will earn the full title of “dredge master”.

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Objectives of Building a Training Simulator

One of the main strategic concerns of dredging companies dealing with projects which are often carried out in distant countries is how to maintain and extend the quality of its dredge masters. The quality of the dredge masters is mainly built upon theoretical knowledge and practical experience.

Furthermore, it is expected that by making the dredge masters more aware of the dredging processes, the production of cutter suction dredgers will also be increased.

Another way of improving the dredging process is by the use of the cutter control system. This highly sophisticated instrument, which is already installed on several dredgers, has already proven its success on board.

On the simulator, special attention will be given to the cutter control system in respect to familiarisation with and tuning of the system to maximise the use of this instrument.

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The Advanced Way of Education

Being aware of the disadvantages of the traditional education programme, Boskalis started the development of a training programme in which the training simulator for the cutter suction dredger is the key component. This training simulator contains the latest developments in R&D translated into theoretical knowledge of the dredging processes. Furthermore, this training centre has at its disposal a Computer Based Training facility and a completely refurbished set of instructional materials, both attuned to the simulator assignments.

In developing this training simulator, the following goals were achieved:
1. the threshold relating to classrooms was removed; and
2. an environment familiar to the dredge master was created.

In particular the second goal set high standards for the requirements of this simulator because of the existing level of dredge masters; experienced dredge masters are very familiar with the behaviour of a cutter suction dredger and expect the same behaviour from the simulator (Figure 3).

It is felt that, only by using this way of education, will a dredging company be able to cope with the tremendous developments that are already taking place and those expected to take place in the near future. Both the requirement for understanding of the dredging process itself and the increasing complexity of the automation on board make high demands upon the skills of the dredge masters.

There has been a clear division between the different approaches to instructing a dredge master with different levels of experience. The most experienced dredge masters already have a high level of practical knowledge, so it is only necessary to add theoretical knowledge in order to broaden their view of the dredging process. The translation of this newly gained theoretical knowledge into practice will take place on the simulator.

At the lowest level the training will concentrate on the practice of dredging. The theoretical knowledge acquired at the dredging schools should be sufficient to form the basis for training on the simulator.

Training with a Simulator

In educational settings, simulators are frequently used for training in the use of standard procedures. A major advantage is the acquisition of hands-on experience in a safe environment. Moreover, simulators can be used to assist in the comprehension of complex processes (Njoo, 1994). The main objective of the cutter suction dredger simulator does not involve training in using procedures but focuses more on the transfer of expertise in the dredging processes from headquarters to the dredging site (Figure 4).

The main target group consists of dredge masters with years of on-the-job experience. They already have a command of procedures and skills for operating cutter suction dredgers. To enhance their performance they have to be offered the opportunity to learn about the latest developments in dredging and practice new working methods. Therefore, instruction with the simulator emphasises:
– acquisition of advanced knowledge;
– understanding of new insights in the dredging processes; and
– application of the acquired skills in practice.

The Installation

Training Simulator

Because the emphasis of this paper lies on the educational aspects, only minor attention will be given to the dredging aspects of the simulator; a brief description of some background on the dredging processes involved follows.

Based on existing and newly gained knowledge of R&D, mathematical models have been developed which describe the following subjects:
2. Movement of the dredger.
5. Generation of spillage.
6. Pumping process, including the suction and discharge processes.

In order to make the interaction between cutter and soil as natural as possible, the seabed and soil characteristics have to be specified in detail. The size of the
During development of the simulator great emphasis was given to the educational aspects. First of all, educational goals were derived from a detailed task analysis of the dredging processes cutting, swinging, suction and pumping and overall optimisation of the dredging processes. Analysis resulted in educational goals which served as a guideline for design of both software models and training programme.

Secondly, an instructional method was defined that provides a balance between simulator training and instruction in the theory of the dredging processes. Dredging theory is not offered in isolation but is always presented in combination with a practical assignment on the simulator. Each assignment focusses on a complete seabed is 200 m x 100 m. The development of excavation faces forms one of the major parts of this model.

The motion of a dredger is simulated by analysing the forces working on the pontoon, ladder and cutter at each simulation interval. These forces originate from the use of spud, ladder winch, side winches, soil interaction and environmental influences like currents and waves.

The process of cutting soil is simulated in detail by calculating the forces which occur in the interaction between the cutter teeth and the soil. Cutter teeth and cutters can be changed during a training session.

Excavated material and water form a mixture, part of which disappears as spillage and is not available for the suction process. At this point the complete system of suction, pumps, suction valves and discharge valves and lines is simulated.

**Instructor Station**

The training session is followed by the instructor on the instructor station. This instructor station consists of two displays. One monitors the essentials of the dredging process and controls the simulation, while the other display provides details of the individual dredging processes: cutting, moving and pumping. All details of the earlier mentioned processes are shown on these screens. These data are presented partly in graphical and partly in numerical form.

The instructor has several handles to control and monitor the training session at his disposal; these controls are:

- **marker:** to locate a special event in time.
- **freeze:** to stop the training session temporarily.
- **intervention:** to change settings during simulation in order to complicate the training session for the dredge master.
- **trigger:** to introduce action when a certain predefined occasion occurs.

This instructor station is also used for briefing and debriefing. The briefing application allows the instructor to prepare the training session together with the dredge master. During this briefing various subjects will be shown:

- bottom geometry and soil characteristics;
- dredger including winches, drives, pumps and such;
- subject of the training session; and
- expected results of the training session.

The debriefing screens are similar to the screens shown during the training session itself. Data presented on these screens are based on the logfile, which contains numerous variables written to this file from each simulation step.

**Educational View**

During development of the simulator great emphasis was given to the educational aspects. First of all, educational goals were derived from a detailed task analysis of the dredging processes cutting, swinging, suction and pumping and overall optimisation of the dredging processes. Analysis resulted in educational goals which served as a guideline for design of both software models and training programme.

Secondly, an instructional method was defined that provides a balance between simulator training and instruction in the theory of the dredging processes. Dredging theory is not offered in isolation but is always presented in combination with a practical assignment on the simulator. Each assignment focusses on a
specific phenomenon of one of the dredging processes and offers the opportunity for practice in a controlled environment. Dredge masters have to recognise the phenomenon, predict its effect, and take action to improve the situation. Furthermore, specific assignments were developed that combined phenomena of the dredging processes and focusses on overall optimisation.

In total sixty assignments were developed. Each assignment represents a defined part of knowledge and skills and this results in a modular structure. A major advantage of this modular structure is that it provides flexibility in the training programme. It offers the possibility to adjust the programme to the needs of different target groups and to individual needs (see section on training programme).

Each training session on the simulator is embedded in a unique framework of briefing and debriefing with the instructor (Figure 5). During briefing, theoretical background on the phenomenon of the assignment is discussed by the instructor and dredge masters. These interactions are supported by instructional materials. These instructional materials, such as workbooks and computer-based training programmes, are specifically developed to correspond with the assignments. Furthermore, the instructor can explain the circumstances of an assignment with support of data and graphics on the instructor station.

When dredge masters have acquired the requisite knowledge during briefing they can train on the simulator. Each assignment involves a scenario of actions for the dredge master. The instructor can monitor the dredge masters’ actions with specially designed instruments on the instructor station. Basically, the instructor does not intervene in the learning process of the dredge master. Interference is only allowed when the action of the dredge master will lead to situations in which the intended phenomenon does not occur. Occasionally, the instructor has to play other characters such as an engineer.

Finally, the results of dredge masters’ actions are discussed during a detailed debriefing. The instructor can play back parts of the session and provide the dredge master with feedback. Also, standards for debriefing are being developed. Graphics can be used to explain the phenomenon to dredge masters and to illustrate his actions. Most of these graphics are available on the instructor station and can also be printed as an annex in the workbooks. The instructor is primarily a coach of the learning process. Dredge masters are encouraged to discover and explain the effects of their actions by themselves although the instructor may guide them in the right direction and can challenge them by asking questions.

The following case is an example of an assignment.

**Purpose of the Example Assignment**
The purpose of this assignment is to examine the use of one or two dredging pumps in relation to the maximum production achievable. The dredge master is asked to draw special attention to the maximum density and corresponding velocity possible in the discharge line.

*Figure 5. Framework with instructional materials.*
The Briefing Phase:
In this phase the instructor will explain the purpose of the assignment, the details of the equipment used and the bottom and soil characteristics in which the simulated dredging processes will take place.

Equipment:
1. Details and characteristics of the ship used in this assignment. In particular the characteristics of the pumps are dealt with.
2. The discharge lines and characteristics of these lines.

Environment:
1. The bottom geometry and soil characteristics.
2. The dredge profile and the position of the cutter itself in this profile.
3. The position of the dredger.

Examining the knowledge of the dredge master in this respect
The instructor will ask the expectations of the dredge master in relation to the density and the velocity of the mixture in case of using two dredge pumps instead of one. The answers will be reported and compared with the answers to the same questions afterwards.

EXAMPLE:

<table>
<thead>
<tr>
<th>Code</th>
<th>p5.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>switch on 2nd pump</td>
</tr>
</tbody>
</table>

### Information

<table>
<thead>
<tr>
<th>Ship</th>
<th>Standard ship (underwaterpump at 5m depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster</td>
<td>none</td>
</tr>
<tr>
<td>Discharge pipeline</td>
<td>Statical height : 0 m</td>
</tr>
<tr>
<td></td>
<td>Length pipeline : 2500 m</td>
</tr>
<tr>
<td></td>
<td>Diameter pipeline : 800 mm</td>
</tr>
<tr>
<td></td>
<td>Number of ball joints : none</td>
</tr>
<tr>
<td></td>
<td>Position booster : not relevant</td>
</tr>
<tr>
<td>Sea bed</td>
<td>SA-4</td>
</tr>
<tr>
<td>Profile</td>
<td>Prof-p3</td>
</tr>
<tr>
<td>Coördinates lb</td>
<td>– 55 / – 5.00</td>
</tr>
</tbody>
</table>

Initial working method
- Depth cutting layer / Step / Retrack or Change Spud
- layer 1: 15 m / 0.5 / R
- layer 2: none
- layer 3: none
- layer 4: none
- layer 5: none

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Cutting</th>
<th>Gathering</th>
<th>Suctioning</th>
<th>Pumping</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil 1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3500 m³/h</td>
</tr>
<tr>
<td>soil 2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>soil 3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Tide and current: none

Start
- Standard Set Up
- Start situation: Starting up cutter
- Starting time: –
- Automation: CDS
The Running Phase:
The dredge master sits behind the desk and the exercise starts. At first the instructor only uses one dredge-
pump and asks the dredge master to get the maximum out of this configuration. In the course of the process
the mixture velocity will decrease to a level below the critical velocity under the chosen circumstances. As a
result sedimentation in the pipeline will occur.

The proper reaction of the dredge master is to ask the instructor, now in his role as engineer, to start the
second dredgepump.

During the simulation the instructor will ask the dredge master to explain his actions and when necessary he
will give some hints in order to direct the simulation, thus avoiding the simulation moving in a completely wrong
direction.

All actions of both the dredge master and the simulator are collected in a logfile for use in the debriefing phase.

EXAMPLE:

<table>
<thead>
<tr>
<th>Training session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
</tr>
<tr>
<td>Description</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Action</th>
<th>Trainee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch on 2nd pump</td>
<td>hints: watch the following gauges:</td>
</tr>
<tr>
<td></td>
<td>– velocity</td>
</tr>
<tr>
<td></td>
<td>– density</td>
</tr>
<tr>
<td></td>
<td>– vacuum</td>
</tr>
<tr>
<td></td>
<td>– intermediate pressure 1</td>
</tr>
<tr>
<td></td>
<td>– intermediate pressure 2</td>
</tr>
<tr>
<td></td>
<td>– discharge pressure</td>
</tr>
<tr>
<td></td>
<td>– production</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task instructor</th>
<th>Following</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TRAINING PROGRAMME

The training programme distinguishes three educational levels for the simulator:

1. Level A:
   - getting acquainted with the use of a cutter suction
dredger and the simulator.
   - learning about the theoretical background of the
dredging processes (cutting, movement and
pumping).
   - being able to improve the performance of isolated
dredging processes (cutting, movement and
pumping).

2. Level B: as level A plus:
   - recognising and being able to explain all events
which occurred during a simulation session, limited
to one of the isolated dredging processes.
   - being able to optimise the dredging processes
(cutting, movement and pumping).

3. Level C: as level B plus:
   - recognising and being able to explain all events
which occurred during a simulation session
   - being able to fully optimise the entire dredging
process.

Amongst dredge masters, three different experience
groups are identified:

1. First/chief dredge master
2. Second dredge master
3. Third/junior dredge master

The first group (first/chief dredge masters) is expected
to follow courses only for one and a half week. In this
period they will only deal with simulation lessons from
level C. This group has the highest priority with Boska-
The Debriefing Phase:
The main topics which are examined in the debriefing phase are:
- Did the dredge master understand the relations between mixture density, mixture velocity and outgoing pressure and the use of an extra dredgepump?
- Did the dredge master take the necessary steps to achieve a higher production?

The instructor will make use of the logfile to explain the phenomena which occurred during the simulation. The logfile is made visible by means of a set of screens comparable with the screens used during the run phase by the instructor. Each of these graphs can be printed.

The dredge master will be confronted with his expectations during briefing concerning the correct relation between the density and velocity of the mixture in respect to the use of one or two dredgepumps.

**EXAMPLE:**

<table>
<thead>
<tr>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code       : p5.1</td>
</tr>
<tr>
<td>Description: switch on 2nd pump</td>
</tr>
<tr>
<td>Points of attention : yes no</td>
</tr>
</tbody>
</table>

**Optimal**

<table>
<thead>
<tr>
<th>Depth cutting layer / Step / Retrack or Change Spud</th>
</tr>
</thead>
<tbody>
<tr>
<td>layer 1</td>
</tr>
<tr>
<td>layer 2</td>
</tr>
<tr>
<td>layer 3</td>
</tr>
<tr>
<td>layer 4</td>
</tr>
<tr>
<td>layer 5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Capacity expectations</th>
<th>Cutting (m³/hr)</th>
<th>Gathering (m³/hr)</th>
<th>Suctioning (m³/hr)</th>
<th>Pumping (m³/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>soil 1</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>3500</td>
</tr>
<tr>
<td>soil 2</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>soil 3</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

**Realised**

<table>
<thead>
<tr>
<th>Depth cutting layer / step / Retrack or Change Spud</th>
</tr>
</thead>
<tbody>
<tr>
<td>layer 1</td>
</tr>
<tr>
<td>layer 2</td>
</tr>
<tr>
<td>layer 3</td>
</tr>
<tr>
<td>layer 4</td>
</tr>
<tr>
<td>layer 5</td>
</tr>
</tbody>
</table>

<table>
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<tr>
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<th>Cutting (m³/hr)</th>
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<td>–</td>
</tr>
<tr>
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<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>soil 3</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
lis and it is expected that the complete group will have visited the simulator within one year.

The second group (second dredge masters) already has some theoretical and practical knowledge of the dredging process so the programme comprises only the levels B and C. In this case the duration of the programme will be two weeks. The training of this group is scheduled to take two years.

The most extensive training programme has been set up for group 3 (third/junior dredge master). They will broaden and deepen their theoretical knowledge of the dredging process and gain practical experience on a simulated cutter suction dredger. Third/junior dredge masters will follow all levels from A to C. Each of these levels will take four days at the simulator. These courses are scheduled over a period of approximately two years.

**Conclusions**

Benefits of the cutter suction dredger simulator are expected to be improvements in communication, control of the dredging processes, and most of all in production.

It is possible to acquire information on the results of the simulator evaluation at four levels (Thijssen, 1994):
- learning processes,
- learning outcome,
- performance at the workplace, and
- trading results.

At the time of the preparation of the present paper results were not yet available but they will receive attention in the near future. First, learning processes and outcome will be evaluated. Results of this evaluation will be mainly used for improving the simulator training programme.

**Learning processes**

Several methods can be used to evaluate the learning process of dredge masters during training. Commonly, subjective measurements such as questionnaires in which dredge masters are asked to comment on their experiences with the training programme, instructional materials and instructor are used. The major advantage of this type of evaluation is that dredge masters are given the opportunity to express their opinions.

For the current training an additional method is used. The instructor is given the specific task of monitoring the learning process of an individual dredge master. During briefing, the instructor asks the dredge master to analyse the situation and to predict the results of the intended actions. Subsequently, during debriefing after the simulator session the instructor asks the dredge master to reflect on the analysis, predictions and actions. Consequently, the instructor does not only evaluate the learning outcome but can also assess the learning process of an individual dredge master. This information is important when adjusting the training programme to the individual needs of a dredge master.

**Learning outcome**

At this level the knowledge and skills of the dredge masters acquired during the simulator training are evaluated. The most common example of this type of evaluation is an examination. For the current training programme, which aims at understanding and enhancement of performance at the working place, an examination of a practical nature is essential. An option is a simulator test session in which dredge masters are asked to perform in a complex situation. Essential performance indicators should be selected to measure learning outcome in a simulator session and the workplace itself.

To make an accurate evaluation of the contribution of the simulator training a pre-test/post-test design is necessary. A dredge master’s level of competence is then tested before and after a part of the training. Timing of the post-test is important. Testing after a period of time has elapsed will probably give a more reliable measurement than directly after the training.

At an individual level, results of an examination may affect continued participation in the training programme, e.g., if a dredge master fails the test he has to do some retraining before progressing further in the training programme.

At a later stage, when the simulator training has been improved and performance indicators have been validated, performance at the workplace and trading results can be evaluated.

**References**

Njoo, M.K.H.

Thijssen, J.G.L.
Bohn Stafleu Van Loghum, Houten, The Netherlands.