How is the Profession of Excavator Operator Changing? The Demands of Digitalization and Automation of Construction Machinery from the Operator's Point of View

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Abstract. New technologies and digital solutions are currently rapidly entering the construction machinery sector. These include (partial) automation solutions for machines and the implementation of the first autonomous construction machines, which no longer require machine operators. The first of these can help relieve the personnel shortage in the future, but qualified skilled workers will still be needed to operate the construction machines. The qualification requirements will increase massively due to the increasing complexity of machine technology and the use of new technologies. Efficient and, above all, safe handling of the new machines and construction processes will be achieved not only by integrating new technologies, functions and machine types into the training and qualification content, but also by adapting the content of these training and qualification programs to ensure a high level of acceptance among operators.

This publication deals with the changes that operators are facing as a result of the digitalization of their occupation and analyzes the resulting challenges for the training and further education of machine operators on the basis of an exemplary activity.

Keywords: training · construction machines · interactive simulator

1 Introduction

As an essential element on the construction site, construction machinery significantly determines the efficiency and effectiveness of construction work. Between the increasing requirements of the construction industry (user side) and new technological offers of the machine and component manufacturers, constantly improved or newly developed machines are brought to the market. In the course of advancing digitalization, new types of systems, components, solutions and approaches are also entering the construction machinery sector and opening up forward-looking development potential. Digitization and the connectivity of construction machinery and construction sites are bringing

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together the construction industry, telecommunications and the machinery. The establishment of "smart" products and services is a central field of action for the development of innovative business areas and the exploitation of efficiency potential in the technology leadership around Industry 4.0 [1]. In construction practice, the implementation of this claim has accelerated significantly in recent years. This publication deals with the digitization of work in the construction machinery sector. As a result, the digital content in the construction machinery sector will be highlighted and the resulting content for the job description of a construction machine operator discussed.

2 State of the Art

When considering new technologies for construction machinery, it is important to take into account the various subsectors that have either been modernized by alternative solutions or have become necessary by the increasing technological demands placed on machinery and processes [2].

These areas include the sensor equipment of the machines. Sensors are used to detect the position of the machine and the work equipment, to recognize people and objects in the machine environment, to record the machine status and to monitor the work process. Another area is the communication between machines (M2M) and within a system (e.g. fleet management system). In this area in particular, new fields of application are being created or have already been created through the use of new technologies, which will permanently change the operation of the machine and the execution of the construction profession. One example is a telematics system that processes and stores machine data and makes it available for retrieval. This data is used to enable applications such as condition monitoring, communication with attachments tools or the above-mentioned fleet management system. Drive technology is a subsector in which the use of new technologies has been particularly dynamic in recent years or is currently being developed. In this context, manufacturers are focusing on electrically driven construction machinery in order to meet future regulatory requirements. These changes generate completely new demands for the operators in terms of the start-up, maintenance and operation of the machine. Another issue is the human machine interface. Here, both the various machine manufacturers and the system developers are constantly coming up with new service and work place concepts. In particular, XR applications enable the operator to interact with the machine or process in new ways. The automation of the entire machine or only of individual activities is another area that has massively changed and will change machine operation. In the future, the operator will no longer carry out the process himself, but rather monitor it, whether on the machine or in a control station. This overview is deliberately very broad in order to illustrate that the digitization of construction machinery is very complex and that the changes that will result for employees will be just as complex. These issues can also be observed in other industries, such as agricultural technology [3] and many others. In [4] for example, selected occupations are analyzed in this context. When analyzing the challenges that digitalization causes for operators and, further on, for training requirements, it is useful to analyze individual problem situations [5]. For this reason, the following section examines an exemplary activity in order to show which requirements arise for the operators and, in the next step, also for training and further education.

3 Analysis of the Technological Transformation

This section uses the example of an earthwork building (e.g. digging a trench) to show the developments in the construction machinery sector and, based on the state of the art, to analyze the changes of new technologies for the work contents. The individual activities required to build the structure are analyzed and their implementation is shown in 4 technological expansion stages. For this purpose, the contents of the construction equipment training, technologies available on the market and current trends are used as a basis for the elaboration of the technological transformation. Methodologically, this content was developed in a multi-stage process based on [6]. This included a literature review to determine the current state of the art and the initial identification of new technologies as well as expert interviews and expert workshops with the instructors of training centers.

Depending on the size of the executing company or the construction site, the individual work steps can be implemented by different entities. But even if, for example, the operator does not always take care of surveying the building, the necessary knowledge must be available. In the framework curriculum for vocational training to become a construction equipment operator [7], one item of the skills to be learned is "handling surveying equipment."

This includes:

- Handling surveying equipment, especially angle prism, leveling instrument and laser
- Align straight lines, measure lengths, and transfer and measure heights
- Setting up string and sighting devices and creating and checking right angles
- Measure components according to direction, position and height
- Stake out longitudinal and transverse profiles

Particularly for the "construction of excavations and trenches", a transformation in the work process can be expected or already observed through the use of digital technology. This should be taken into account in the training content. With the introduction of digital terrain models, these tasks can be transferred into the automated machine in the future. For this purpose, the machine needs a planning basis consisting of the digital model of the construction site and the structure to be built. The additional work required includes copying the models into the excavator control system and checking for plausibility, i.e. whether the data shown on the display actually correspond to the structure to be built by the machine. Depending on which system is used, it may also be necessary to calibrate the working equipment at a reference point. In the following, 4 time-dependent technology levels are taken into account for the execution of the job considered here, and the associated activities of the operator are given. These start in the past, i.e., with a conventional machine and end in the future with the automated machine with environment detection. The technology levels focus on all relevant areas starting from the machine via the work process as peripheral activities, such as the building surveying.

3.1 Level 1 Past/Present

The trench is constructed with a hydraulic-mechanical pilot-operated excavator. In advance, the terrain was surveyed and a site plan and an allowance were prepared.

Using a total station, GNSS receiver or rotating laser, the surveyor determines the necessary coordinate and measurement points and documents this. Based on this, the planning office draws up the necessary construction plans. For the actual process of digging, the following activities result for the operator:

- Reading and understanding the construction plan (paper)
- Setting up the construction site and transferring the construction plan to the terrain
  - Operating surveying equipment (angle prism, level and laser)
- Operation of the excavator with joysticks
  - Knowledge of actuator function, tool selection
  - Knowledge about hydraulic system, connection joystick deflection-machine behavior, knowledge about correct process sequence
- Control of the structure/measurement of the trench
  - Operation of surveying equipment (angle prism, leveling instrument and laser)

3.2 Level 2 Present

Currently systems are offered that visualize the work progress for the operator. The position of the work equipment is detected by sensors and shown on a display in the operator's cab. For this purpose, the terrain surface is defined as the starting position with the touching of the work equipment (driving to reference point). The target depth is set by the operator. By displaying the current position, the operator is supported in reaching the target depth with greater accuracy and more quickly. The activities to be performed by the operator are not substituted by this system. Rather, additional activities become necessary:

- Handling of the system interface
  - Define reference height terrain
  - Define reference depth
- Reading and understanding the digital display
  - Structure and function of the sensory equipment
  - Procedure in case of system errors, maintenance

3.3 Level 3 Present/Future

An extension of the system in Sect. 3.2 is offered in current machines as an assistance function to the extent of depth limitation or partial automation of individual actuators. In the latter case, the operator only has to perform the boom movement, and the bucket and boom cylinders are controlled in such a way that a defined height is maintained at the bucket. These systems will gain further market acceptance and will be available on many machines in the near future. To achieve this, it is necessary for the valve pilot control of the hydraulic system to be electrohydraulically controlled. This function reduces the completion time of the building, increases safety and improves the quality of the structure. Additional operations are not necessary in comparison with the above mentioned ones. The definition of the position of the working equipment is also realized in these systems by moving to a reference point, which must be performed additionally. Another possibility is shown in Fig. 1 using a laser receiver.

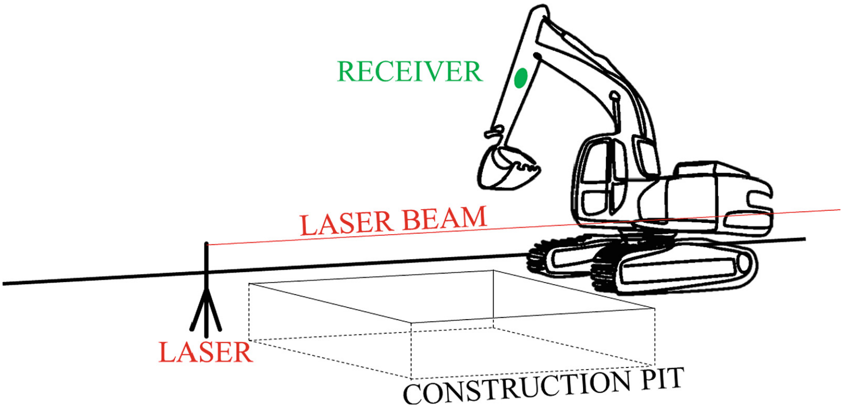

Fig. 1. Referencing the work equipment with laser receiver

3.4 Level 4 Future

In the future, the process will be (partially) automated. The terrain of the construction site will be surveyed at the start of planning and during the construction phase for documentation of the construction progress (e.g. by aerial flight with a drone). The resulting DTM and a 3D model of the trench are then transmitted to the control system as the basis for the task. This can be done either by the operator and a storage medium or via a cloud connection (telematics system). The operator sits down in the machine to start work and is shown all the necessary data on the control display. In the first step, the machine is located in the construction site environment (e.g. GNSS) in order to reach the target location of the building. Sensors of various types also determine the position of the work equipment. The process is fully or partially automated. Depending on the design, the operator only takes over a supervising activity or still has to specify individual joystick control signals. The activities to be performed by the operator are considerably extended:

- Operation and understanding of the system
- Perform GNSS-supported machine positioning

  – Establish/check GNSS reception

- Transfer 3D model to controller
  - Understand data flows
- Estimate geological soil properties
  - Input to excavator control system

Summarizing the above-mentioned stages, Fig. 2 shows the new or transformed activities in the creation of an earthwork. The left-hand side shows the usual construction process, which was carried out in the past and is still being implemented in the same way today. The right-hand side shows the change in this task due to digitization and the associated systems, which are already being used as mentioned above or are expected to be used in the future.

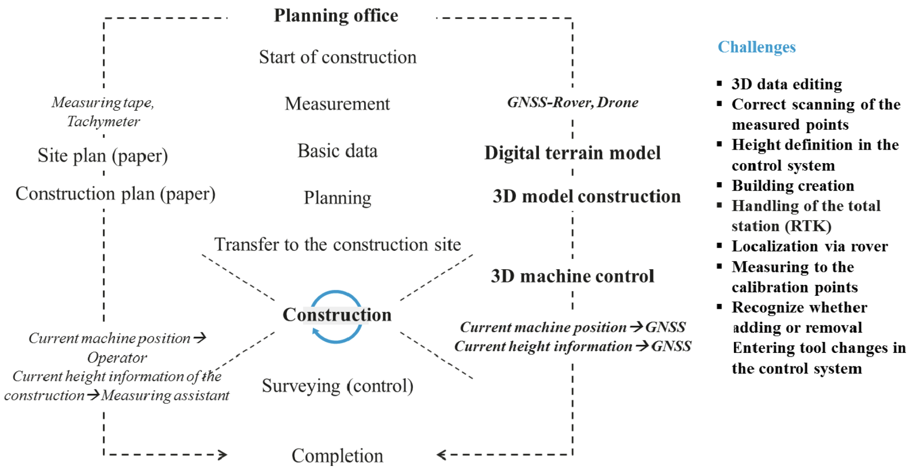

Fig. 2. Change in the tasks due to digitization when creating an earthwork

3.5 Challenges Due to Digitalization

The analysis shows how the complexity of the construction machine operator's job is increasing. Even the comparatively simple construction of a trench is becoming significantly more demanding due to the use of modern machines, sensors and surveying technologies. For the operator, this means that new work steps are added to the familiar ones or entire work steps are substituted. Two fields of action arise in order to integrate the new technologies into the application on the construction site. On the one hand, these are the workers with professional experience and, on the other, trainees.

For experienced workers, the use of digital solutions can become a challenge when activities such as data preprocessing on a laptop or on a machine are added, for example, to create a 3D building model. There is an acceptance barrier here that should not be ignored, and this can lead to the systems not being used, especially by older employees. The experience of these users shows them that they have previously managed well without the systems that require digital work steps. Assistance functions are also not primarily part of facilitating systems for experienced construction equipment operators, even if the work could be carried out quickly and without problems in the past. This could change in the future, however, if more and increasingly complex tasks can be processed by the systems and not only relatively simple ones, as it has been the case up to now. In any case, there will be an increased need for training, especially in order to explain the advantages of digital solutions to the operators (e.g. excavator scales) or the owners (e.g. fleet management system).

The challenges for trainees are not so much due to a lack of acceptance by young operators as they are in the content of the training. Often, the new systems are not yet part of the curriculum, which can have various reasons. On the one hand, the framework curriculum does not yet provide for them, and on the other hand, the systems are not present in the company or in the training center and are therefore not known to the trainers. This requires a modernization of the teaching content, which in turn requires a new approach to teaching the new content. The claim to integrate current and future technologies as an object of appropriation in training and at the same time to develop new approaches to the (digital) design of teaching and learning processes, which includes the technical and didactic training of training personnel, implies a decidedly work task-related teaching and learning. The creation of task-related teaching-learning concepts requires the selection of exemplary sections of reality and the analysis of the teaching and learning potentials contained therein. First and foremost, the knowledge, skills and abilities that must be retrievable in the context of routine tasks and activities must be differentiated from those that are necessary in the context of problem-oriented tasks. Afterwards, an analysis from a didactic point of view has to take place in order to structure the knowledge. Subsequently, relevant factual and action-related contents are to be selected and appropriately combined with each other. This must be done in a high level of detail for different tasks. This shows that the implementation of the necessary teaching content is highly complex and costly from a didactic point of view. For further details, please refer to [5] where exactly this didactic implementation was discussed.

4 Summary

Intermediately the use of autonomous construction machines, which no longer require an equipment operator, is limited to a few areas of application. Automation solutions can therefore partially counteract the shortage of personnel, but qualified skilled workers for the operation and maintenance of construction machinery are still indispensable. However, with the increasing complexity of machine technology and the digitalization of the entire occupational field, the qualification requirements will increase massively. It is important to integrate new technologies, machine types and functions into training and qualification measures at an early stage in order, on the one hand, to teach the safe and efficient handling of new machines and construction processes and, on the other hand, to increase the acceptance of new technologies among all those involved in the process. This results in an increased need for new training and education concepts, which should be complemented by modern equipment. In addition to the latest machine technology, this includes modern training tools such as interactive simulators and blended learning methods, which support both the scope and the quality of the training. This is realized through realistic training as a precursor to training on capital-intensive real machines. In addition, new and particularly critical situations can be trained on interactive simulators. This is often associated with a high risk for man and machine on the real machine.

Not only the operation of construction machinery is changing with technological change, but also the maintenance of the machines. Additional electrical and control technology components and completely new types of drive systems and components make it necessary to significantly increase qualifications. In this respect, the necessary activities in the fields of mechanics and hydraulics are not only changing due to knowledge in electrical and control engineering as well as power electronics, but must also be modified at the same time, parallel to technological development, at regular intervals.

The entire job profile of the construction equipment operator will change as a result of digitalization, i.e. the introduction and establishment of increasingly sophisticated, high-tech machines and work equipment. Added to this are changing and digitized work processes. Although the stressful external conditions, such as weather, noise and dust, will remain, the developments could increase the attractiveness of the construction professions for the younger generation. Digitalization can therefore be seen as an opportunity. At the same time, however, it presupposes corresponding innovative training.

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