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Review of compatibility and selection of multiple lever controls used in heavy machinery

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ABSTRACT

The current state-of-the-art of research on use of multiple lever controls in heavy machinery such as underground mining machines, forklifts, excavators and cranes is reviewed. Strong stereotypes for control selection and operation are noted. These controls may be complex due to many similar controls, multi-functions of a control and lack of distinguishing features of controls. Multiple lever controls have a number of serious design problems associated with control selection and direction of motion of the control for a required machine output. Possible solutions to these problems are reviewed and suggestions are given for designs which are more ergonomically sound. The guiding principle for a compatible design is that there is directional compatibility between control movement and corresponding machine output movement. Design for ease and accuracy of control selection requires further research.

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1. Introduction

It is common in mining machinery, and in other industrial equipment such as cranes and excavators, to use a bank of control levers, all of which are of the same length, color and shape and mounted in the same orientation. In many of these designs fore/aft movement of the control is used for many different functions, for example, slew, drill feed, stabilizing the machine, elevating the cutting head and so on. It is suggested that such control arrangements are used for simplicity of installation rather than from good human factors design. Typical examples are shown in Fig. 1a–d for lever controls of mining equipment, cranes and excavators. Steiner et al. (2014) and Steiner and Burgess-Limerick (2015) show other examples of mining machinery. In such arrangements of controls, it is highly likely that there will be incorrect selection of a control for a particular function, unless there are design features that allow the user to better discriminate the correct control such as by having different lengths of each control. Problems may also arise due to incorrect direction of control movement because of incompatible relationships existing between control and machine movements.

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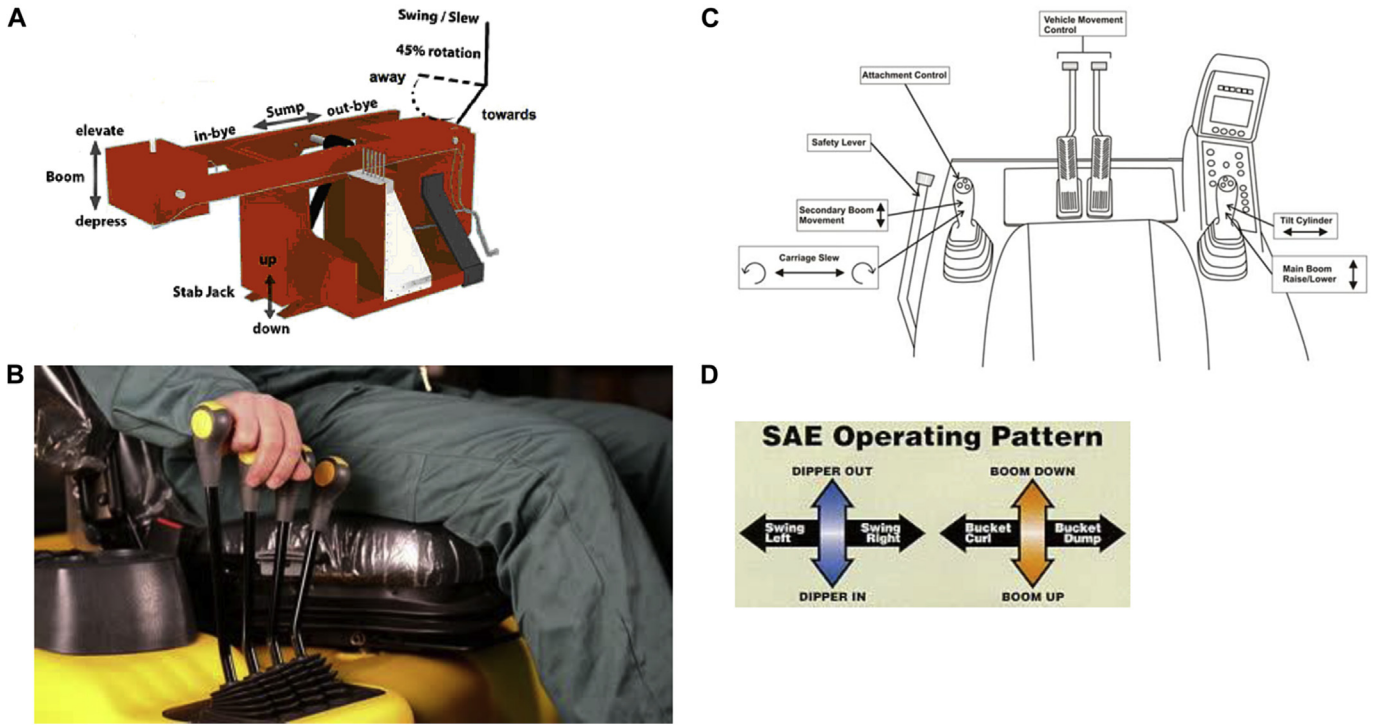

Fig. 1. **a**. Experiment of Steiner et al. (2014) with a large model roof bolting machine. Levers were mounted vertically or horizontally. Corresponding responses were 'away/toward' or 'up/down', respectively. **b**. Forklift lever controls. From Google: Forklift lever controls. **c**.Excavator multi-function control sticks. From Google: Excavator lever controls. **d**. Excavator multi-function control levers SAE standard patterns of operation. . From Google: Excavator lever controls.

Reviewing the research literature reveals that most of the reported research is related to mining machinery (Simpson and Chan, 1988; Burgess-Limerick et al., 2010a,b; Steiner et al., 2014). There is some research related to crane control (Sen and Das, 2000; Bergstrom-Lehtovirta et al., 2009), but little reported for other forms of heavy machinery such as excavators. In one respect this is an interesting situation as it is for the more commonly used form of machines that the least reported research is available. It may be that there is in-house research as there are codes or standards, such as that of the Society of Automotive Engineers of USA (SAE, 2012) illustrated in Fig. 1d, for the actuation of controls for excavators.

There have been several studies reported of control problems in various forms of heavy machinery. Casey (1985) in interviews of tractor operators in the USA and Europe found that of 234 comments relating to the interior of the operator's cab, the majority were related to the operation, location and design of the controls. The author made no specific comment on the form of control or the compatibility of the relationship between control input and machine output. Sen and Das (2000) in a study of 51 electric cranes in India found incompatible controls in almost all cranes, as well as many different patterns of control location and direction of control movement for each of the cranes. Thus, at that time, there was very little adherence to standards or good ergonomic design that allowed operators to control with accuracy for direction of control movement or control selection (Schneider et al., 1997).

1.1. Standards for heavy machinery controls

The SAE standards (SAE, 2012) define control-input/machine-output relationships for heavy machinery such as excavators and earth-moving equipment. It is not known if these standards were experimentally determined or simply based on 'reasonable' expectations. As well, it is unknown if operators can, without excessive control errors, use the multi-function controls suggested in the SAE standards. As shown in Fig. 1d, the left-hand lever controls 'swing' to the left and right and the in/out motion of the excavator, while the right-hand lever controls the boom and bucket motions. The suggested control movements of the standard appear to have good levels of 'directional compatibility', that is, the machine outputs are generally in the same directions as the control inputs.

The directional compatibility is illustrated as follows (refer Fig. 1d).

Left-hand controller: Move control left => slew left; control right => slew right

Move control forward => dipper out; control back => dipper back

Right-hand controller: Control left => bucket close; control right => bucket open

Control forward=> lower boom; control back=> raise boom

Of the four motions of machine output, three may have strong directional compatibility – the machine output of the bucket location follows the control input. Only the bucket open/close motion does not have a strong control/machine relationship. Most manufacturers follow this design standard, although some follow the ISO standard that has the boom and dipper controls interchanged on the right and left hands, other functions remaining the same. Operators changing between machines have difficulty with the different control arrangements; this has been overcome with some manufacturers having a switch that changes the controls between ISO and SAE standards (a number of forums related to the problem are available on the internet).

A further useful standard is ISO 6682: 2004 Earth Moving machinery – Operator's controls (ISO, 2004), which specifically states "The movement of controls in relation to their neutral position shall be in the same general direction as the machine response". This is a statement of the requirement for directional compatibility of the

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