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What is (not) an operator effect in forest work science?

There is no doubt that the operator is one of the key "components" in nearly any system used in forestry (Mola-Yudego et al. 2015; Malinen et al. 2018). However, we need a collective understanding of what an operator effect or rather a human influence really is in forest work science. Most of us probably regard psychological, cognitive, and motor abilities as human influences (or, more strictly, potentially influential human factors or variables) that may affect results in various ways, but it is equally important to consider what is not a human influence. For instance, an operator consciously and recurrently conducts certain working manoeuvres and tactics in specific ways that will clearly affect performance. Should these also be regarded as human influences?

During the era from the 1970s to the beginning of the 2000s Nordic forest researchers published studies on the operator effect relatively frequently (Harstela 1975; Gullberg 1995; Björheden 2001), especially considering that substantially fewer scientific articles were published then. However, for unknown reasons this essential part of forest work research has been largely neglected for more than a decade in the Nordic forest scientific literature. Since an article by Lindroos (2010) that deeply and critically addressed this important issue it has been ignored.

This is unfortunate because in forest work research we typically analyse alternative working methods or technological innovations and even if we are not often directly interested in operators, they impact the results and thus complicate our analyses. Nordic forest researchers have traditionally considered the operator as a block effect in statistical models, and hence applied blocking to account for human influence. In practise this means that each operator applies all alternative technologies or working methods monitored or tested in a study. This is basically correct, but there are many issues to consider and discuss. Here I focus on three of these issues:

1) risks of human influence being confounded with different working tactics,
2) pooling data across the operators in order to obtain generalizable results,
3) defining operator effects as either random or fixed, and whether it matters.

There is a risks of human influence being confounded with different working tactics. Forest work often involves various working methods and habits (hereafter referred to collectively as working tactics). For instance, all forest machine operators use crane and drive machine simultaneously, at least to some extent, but some prefer to overlap work elements more frequently than others. Similarly, the dominant working zone (applied boom reach and angle) varies between

operators. Moreover, some forwarder operators prefer to forward several assortments in a load, while others are more likely to avoid multi-assortment loads, and harvester operators can choose between several dominant felling directions and pile the logs either on both sides of the machine (left and right) or purely on one side. Thus, preferred working tactics vary among operators of both forwarders and harvesters.

In addition, steering manoeuvres involved in any working tactics require psychological, cognitive and motor abilities that vary between operators, and are key elements of human influence. Thus, it is tempting for a researcher to handle human influence and various working tactics collectively as a single effect, without further reflection. However, ignoring the diversity of work tactics also inevitably entails a loss of essential information about the conducted work, which hinders understanding and application of results. Therefore, it is essential for forest work researchers to develop the ability, and take the additional time required, to segregate effects of different working tactics from a purely human influence (even if the distinction can seem vague and it may be tempting to cut corners).

We nearly always need generalizable and representative results. A few years ago, I co-authored a study in which we found conflicting operators' responses to crane automation (Englund et al. 2017). Some consumed more time and other less time when using a partly automated crane. Simply pooling the data across operators, and hence ignoring intra-operator results, would have indicated that crane automation does not affect time consumption. This conclusion would clearly have been wrong. A more interesting question is what should we have done? Simply presenting the raw intra-operator results would not have been sufficient either because we needed generalizable results. However, as we scrutinized the numerical outcomes more deeply, we found a generalizable pattern: Operators who could operate a crane in purely manual fashion relatively rapidly consumed more time, and their slower colleagues less time, when using the partly automated system.

A few years later I participated in another analysis of possible time savings when using an Assortment Grapple (originally "Sortimentsgripen" in Swedish) in different working situations (Manner et al. 2020). This product consists of a standard grapple with an extra pair of claws, providing an accumulating function that facilitates the handling of two assortments during a single crane cycle (hence its name). The objective of the study was to formulate guidelines for working with the Assortment Grapple, specifying appropriate general working situations for operators to use the accumulating function and when to use the grapple conventionally. Again, similarly to the study by Englund et al. (2017), we obtained conflicting inter-operator results. Two of four operators could save time by using the accumulating function in most tested working situations, while the other two tended to slightly struggle with its use. To provide the requested general guidelines, we recommended its use only in working situations in which none of the participating operators lost time and most (three of the four operators) saved time with the accumulating function. In general terms, we pooled operators only within treatments in which the operators' responses to use of the accumulating function were similar (or at least not contradictory).

Should the operator effect be random or fixed in forest work science? Defining worker as a random effect is a widely acknowledged and efficient way to deal with human influence in occupational epidemiology (Lyles et al. 1997; Peretz and Steinberg 2001; Friesen et al. 2006). This can be illustrated using a textbook example of analysis of sleep deprivation effects on workers' reaction times. In epidemiological studies participants (workers) can often beneficially be sampled from the same population. Reaction time deviations from "the population's trendline" are to some extent assumed to be part of the population's random variation. That being said, when we define the participant as a random (rather than fixed) effect we apply partial pooling to shrink differences between the participants (hence the process is also called shrinkage). This issue is treated more com-

prehensively in numerous textbooks and articles (Ghosh and Meeden 1984; Siemer 1997; Gelman and Hill 2007). However, my focus here is on purely pragmatic concerns in forest work science.

In forest scientific time-and-motion studies operator (participants) has been defined as both a random and fixed effect. Because random variation can unfoundedly pose and/or exaggerate inter-operator differences, defining operator effect as a random (instead of fixed) effect can be justified in some cases. However, in contrast to the epidemiological textbook example above, the random variation of an individual human's performance is not the main problem when dealing with human influence in time-and-motion studies. Therefore, defining operator effect as a random one does not in itself provide any quick fix in forest work studies. The key, instead, is to deepen knowledge about inter-operator differences in cognitive, psychological and motor abilities, then (more importantly) address their interactions with alternative working tactics more deeply. Currently we lack consensus even regarding the terminology.

To summarize, datasets obtained by monitoring the work of (skilful) operators sampled from the same population have traditionally been desirable because they greatly facilitate statistical analysis, but such datasets are less desirable from a generalization perspective. Therefore, we should probably rethink our approach slightly and include more heterogeneous groups of operators in our studies to obtain more generalizable results. However, this would also require rethinking of the analyses. Pooling operators completely across the whole dataset would often be completely unfeasible, but pooling operators within specific treatments for which there are no strong inter-operator variations in trends may be possible. In addition, we might pool similarly responding operators into the same groups, thereby generating generalizable operator profiles.

Segregating effects of working tactics from human influence is undoubtedly difficult sometimes. However, the simple statement that (for example) operator B is more productive than operator A is not very informative. The key issues are why operator B is more productive, and whether it is due solely to differences in cognitive, psychological and motor abilities or partly to differences in working tactics. Thus, the minimum requirement in every forest work study should be at least to describe each participating operator's working tactics.

Moreover, automatic data gathering opens new possibilities to analyse working tactics during real-life logging operations. For instance, a datalogger can record the forwarder's crane reach and angle as it grasps a pile to be loaded, or those of a harvester-head as it grasps a stem to be felled and bucked into logs. Moreover, for harvesters it would be technically possible to collect diverse variables such as felling direction, and piling logs either on one side or both sides. These recordings could potentially be used as continuous variables to describe working zones and tactics. Thus, hopefully it will soon be easier to separate effects of alternative working tactics and a pure human influence even in follow-up datasets.

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