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HUMAN INFLUENCES ON HARVEST OPERATIONS

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Abstract: *The individual performance of a harvester operator, which is considered decisive in manual or motor-manual activities, is often disregarded in mechanical work. Practical experiences, however, indicate that the machine operator is a crucial factor influencing the performance of the harvesting system. Hence, calculations and planning that do not account for the individual performance will potentially introduce errors.*
Time studies and production logging files of over 50 individuals were collected over a period of three years. Production data and drivers' performances were analysed and compared, and the influence of human factors described in a qualitative and quantitative manner. A performance level was calculated for each harvester operator and incorporated into productivity models. In addition, the effects of learning curves, performance potential and other factors influencing the operator's performance were identified. Study results help to better understand the general influence of machine operators and to simplify the planning for harvesting operations.

1. Introduction

Single grip harvesters may reach very high productivity levels but are very expensive forestry machines. Therefore, they have to work very efficient. Another influencing factor on the productivity of a harvester system is the individual performance of the harvester operator. This is often disregarded when considering mechanical work performance. As Kirk et al. (1997) mentioned: "A skilled operator is essential if the investment in the machinery is to be maximized by the contractor." Calculations and planning that do not account for the individual performance will potentially introduce errors, which have not been quantified yet. The inter-individual, intra-individual and temporal observed variability in the performance level of the operators can be very high.

The relation between productivity and experience is called a learning curve. To measure the experience of a harvester operator directly still remains a problem. Currently, only productivity, time and some influencing factors can be measured. The assumption is that the more time the operator spends the more familiar he/ she will become with the machinery, hence his/ her skill level increases. However, this does not presume that the productivity of the whole harvesting system increases proportionally. At the same time, other influencing factors such as age and health of the operator or age and condition of the machinery can decrease the productivity level. The "real" learning curve is often not quantifiable. For this reasons the learning curve often is interpreted as the relation between productivity and time or cycles of work.

Analyses of learning curves from harvester operators are rare. Stampfer (1999) suggested dividing the learning curve effect into two phases: The first phase is called the learning phase and the second one is the working phase. This is equivalent to the description of the so called “inexperienced” and “experienced” operator. The literature often describes a threshold between these two phases as being eight to 12 months of operating work. Most current analyses are restricted to the first phase, the training in the simulator. The second phase is often disregarded as a consistent performance level of the operator is assumed.

The function of the productivity can be simply described as follow:

$$P = f(tv, O, t_o) \quad (1)$$

where P, tv, O and t_o are the productivity of the harvester system, tree volume, operator and work time (Experience) of the operator.

In this presentation, an attempt is made to investigate the relationship between productivity of the harvesting system as a whole, human skill and time.

2. Material and Methods

To proper analyse the productivity of different operators, (52) time studies and logging files were conducted. The number of recognized stands is 4437.

2.1 Stands, Machineries and Operators

The experimental study sites were located in Germany with focus on East Germany and Bavaria, South Germany. For comparability, only pine-dominated stands were selected for the analysis. The harvesting system included thinning and marked trees in young stands with a CTL single-grip harvester. For the most stands this was the first thinning and strip roads were built. Distances between working lines are 20 to 24 meter. Only sites with a slope less than 10% were considered.

Over 90% of the harvested trees were pines (*Pinus sylvestris* L.). Other tree species included spruce (*Picea abies* (L.) H.Karst. - 6.1%), larch (*Larix decidua* Mill. - 0.6%), birch (*Betula pendula* Roth - 1.7%) and hardwood (0.7%) (Figure 1).

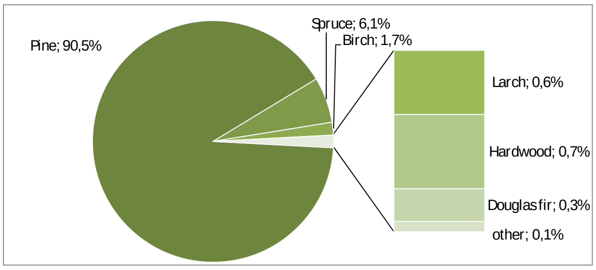

Figure 1 Allocation of tree-species

The information of 52 operators was collected but only 32 were considered for the analysis due to the following rules:

- Machinery (only three types of harvesters for small diameter thinning were selected: John Deere 1070, Valmet 901 and Ponsse Beaver)
- tree stands (spruce, larch and hardwood dominated stands were not considered)
- Harvesting system (only thinning was considered rather than clear-cut or wind throw-areas)
- Operating sites (number of the working areas had to be more than 15)
- Other factors such as: Forwarder operators work or incomplete information about the operator

There are differences in the operators' educational and practical background. Some of the operators had taken a harvester education program or course at a forestry academy. These courses varied from one day to seven weeks. More than half of the operators (56%) had an additional three years of training. Some (28%) had completed a different education such as mechanics, carpentry or butchery and learnt harvesting on the job-site. The time worked on the harvester varied as well from beginners to well experienced operators that had been working in this field for seven years and longer.

2.2 Logging Documents and Time Study

Most data were collected through the data logging systems of the harvester. Additional information came from time studies on sites.

The date logging system is based on the StanForD-Standard. The data are stored in defined files depending on the system and include the following data (Skogforsk, 2007):

prd	Production (primarily harvesting production data).
pri	Production-individual, harvesting data concerning each individual log and stem is registered.
drf	Operational monitoring data, covers both time (tid) and repair (rep) data since major update in 2003.
stm	Stem values, measured length and diameter values

Additional information on times, dates, harvesting data, operators and software is also included. For example, the types of time are Effective time, G15-time, Move-time, Runtime, Work time and Repair time. The G15-time was used for all of the analyses.

A big problem is the inconsequent realization of the StanForD-Standard. The variances in software types and versions installed in the harvesters made it very difficult to analyse the data.

For additional information, a new semiautomatic forest time study method had been used for the harvester, which is described in Purfürst and Erler (2006). A combination of sensors and intelligent software is recording data of motion and working. Several sensors are installed on the harvester, boom, and wheels. The movement of the harvester head is recognized by an inertial-sensor-system. The whole sensor system is independent of the type of harvester and can collect data over hours and days without influencing the work of the harvester operator.

2.3 Data Analysis

A program written by the author analyses the huge number of StanForD files, by parsing the different variables. This data was written into a database. As the size and duration of the operation per stand differs, the information had to be harmonized and weighted, based on the time variable. The database program splits every stand into 'x' amount of stands depending on the time (G15). This can happen in different ways depending of the used time period: The higher the split time period the fewer amounts of data are produced and on the other hand, the lower the split time period the more data are produced that the statistical software has to handle and to calculate. The preferred time period to split the data of the stands is one hour of G15-time. These data were analyzed with standard statistical programs independent from the real stand-size. The analysis of the production data is based on the stand, weighted by time.

The information about stems, times and harvested volume were used to create performance information for every stand and operator for a specific date. For every operator, a regression of productivity correlating with the tree volume was calculated. The base correlation can be expressed as a logarithmic curve:

$$P = b_0 + b_1 \ln(tv) \tag{2}$$

where P, b_0, b_1 and tv are productivity in m³/h, variables of the formula and volume/tree.

To calculate the variance of the performance level over time, the relative productivity was calculated using:

$$RP = \frac{P(tv)}{PM(tv)} * 100\% \tag{3}$$

where RP, P, RM and tv are relative productivity in percent, real productivity in m³/h, productivity of the model (logarithmic regression) and volume/tree.

This relative productivity can be calculated based on a single operator or of the entire data set.

3. Results

More than 9 million stems harvested by the 52 operators were collected for this study. For comparability reasons (see above), only 6.2 million stems from 32 operators were analyzed, which represents approximately 0.9 million cubic meter (m³) of harvested wood. The mean volume is 0.15 m³/tree. Data from the logging documents were recorded during December 2003 and December 2006.

The mean productivity of the overall data set is shown in Figure 2. The number of recognized stands is 4437. The influences of the stands on the regression are weighted based on time. Results show a correlation between the productivity (m³/h; G15) and the volume of each tree. Nearly 70% of the variation in productivity can be explained with the tree-volume ratio. The logarithmic regression is used as a basic function of the relative productivity.

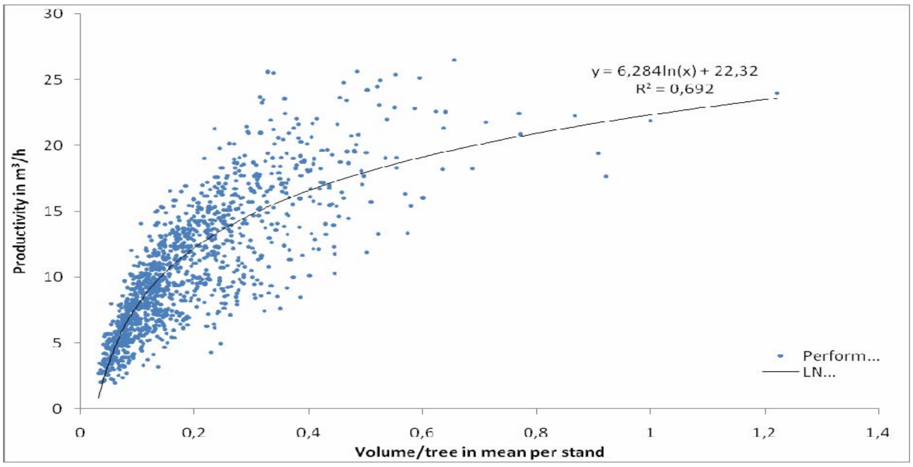

Figure 2: Mean of overall productivity

Figure 3 shows the mean of the overall productivity in combination with the standard deviation, the maximum and the minimum. There are large differences between the harvester operators and their performance level. This cannot only be explained by the level of experience. The individual learning curve, motivation and human abilities are also important. The best performance shows twice the productivity when compared to the worst performance. The standard deviation is 26% (relative to the mean).

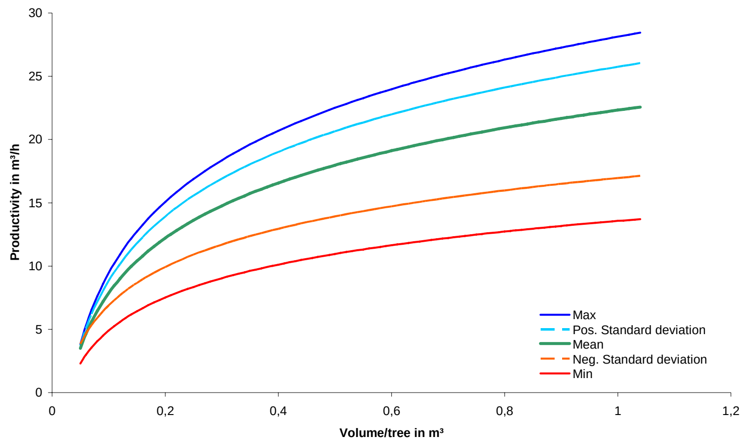

Figure 3: Dispersion of the mean productivity

Figure 4 and Figure 5 show examples of different learning curves. Relative productivity correlates in different ways with the time needed to harvest a stand. The blue dashed line shows the relative productivity based on the overall population productivity from Figure 2. The red line is based on the individual created regression of every harvester operator over the entire period.

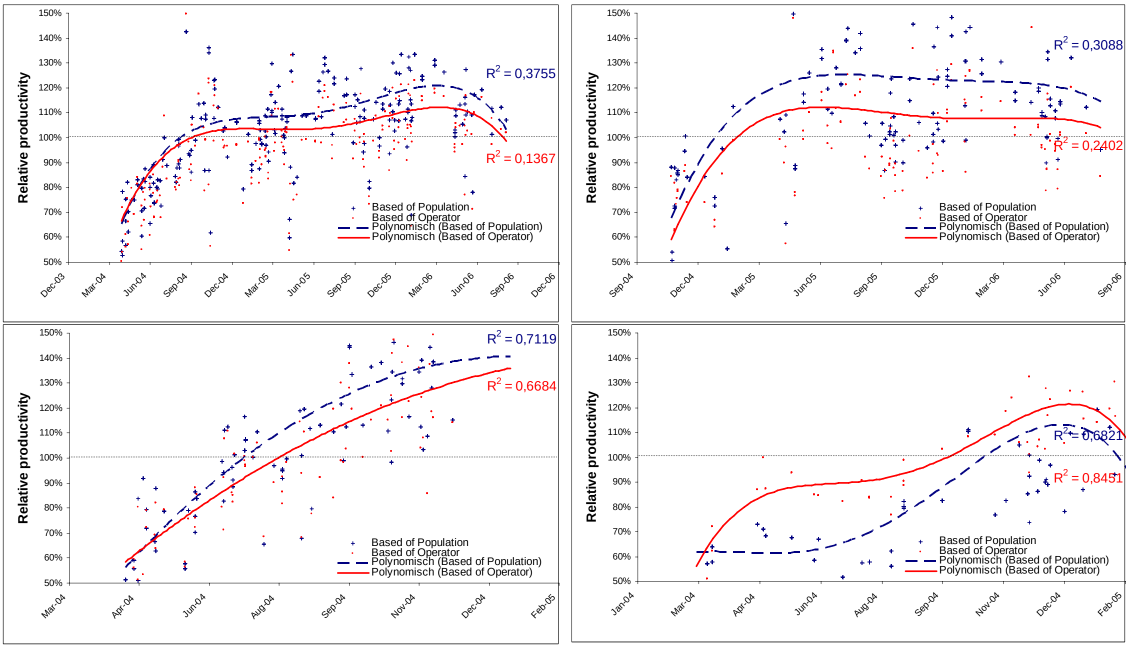

Figure 4: Learning curves I

Every graph in Figure 4 shows the operator from the beginning of his harvester experience onward. Nearly every operator started with a performance level (based on the mean) of about 50%. The speed to reach the working phase varied from six to nine months.

The first stagnation occurs after about six to nine months and is often followed by a little decreasing and a increasing. At last, the productivity does not level out to a predetermined stage. A fluctuation in the performance level is recognized by every operator. This might be due to intra individual performances or external influences such as machinery or weather, which are very difficult to control.

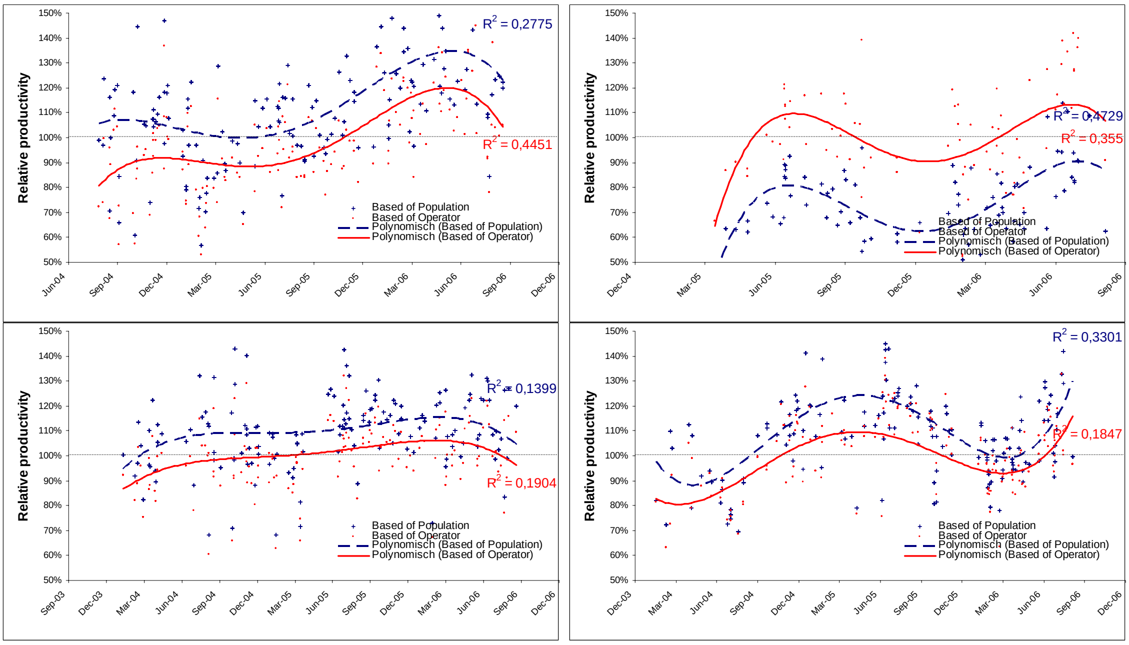

Figure 5: Learning curves II

Inter individual differences are well shown between the operators (Figure 4 bottom left and Figure 5 top right). After nine months, one of the operators works with a level of 140%, another at a level less than 85%.

Figure 6 shows a common graph of the relative productivity of two operators working on the same machine in shift work. Operator No. 16 started in April and his co-worker (No. 15) started six months later. Both are skilled forest workers with an additional six weeks of harvester education including training in the simulator and on the site. Both were beginners when they started.

The operator No. 15 was improving faster in his first six months than his co-worker. The harvester operators can read their daily production level and have a direct comparison among each other. This might be one of the reasons for his motivation and rising productivity while operator No. 16 remained consistent after half a year of operations. After some time both experienced operators had nearly the same level of performance, 20 percent above average (Figure 6). This is a typical characteristic of shift workers and was measured in some cases. The decrease in productivity in the fall of 2006 is due to mechanical problems of the machine.

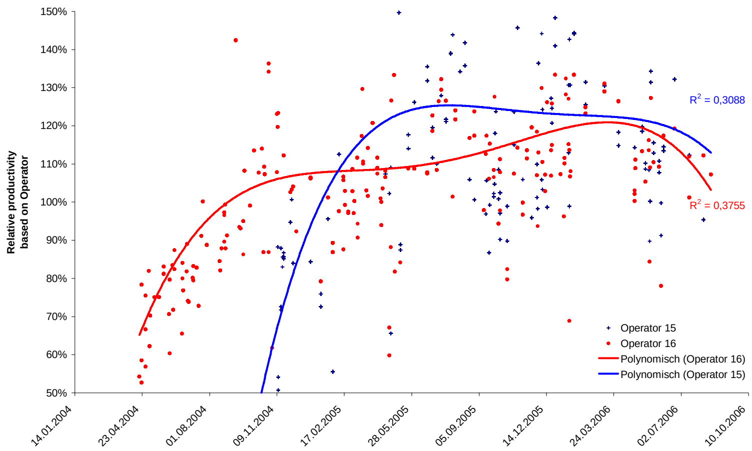

Figure 6: Relative productivity of shift workers over time

Figure 7 shows the learning curves of one operator over a nine month period. After six months his productivity increased rapidly and he reached the working phase with nearly twice the productivity. The production loss of the training phase compared to the working phase is 20% to 30% of productivity. This means nearly 2 to 2.5 months of productivity.

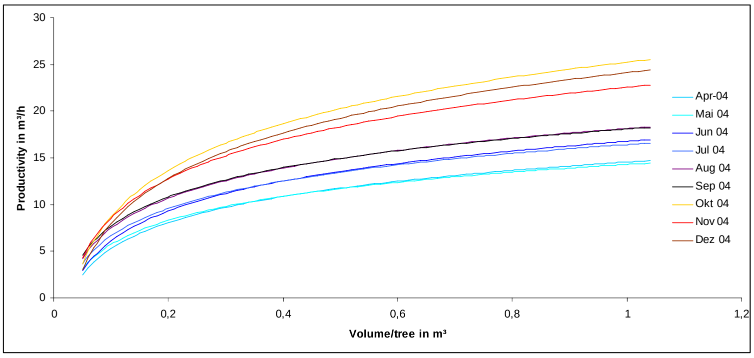

Figure 7 Learning curves of operator No. 27 in his first nine months

Significant correlation between the performance level of the operator and the non-productive times such as repair time could not be recognized. This means that the correlation between the productivity of the entire harvester system and the individual performance level is linear and can be expressed as follows:

$$P = PL_{G15} * MP \qquad (4)$$

Where P, PL_{G15} and MP are productivity of the harvester system, performance level of the operator calculated from the G15 and mean productivity.

4. Discussion

The calculated performance level of the harvester operators does not follow the Gaussian distribution as described by Erler (1985). Erler's research focused on chain saw workers. The amount of data from this study however, is not considered representative enough to draw conclusions to a larger scale of forest workers. On the other hand, looking at manual forest work, one assumes that the differences in performance derive from the fact that a person works more or less efficient and quick. It means that the efficiency is nearly 100% reflected in the productivity of the system. With regard to mechanical work, the influence of the operator's decreases and the productivity is mainly determined by the performance of the machine. This factor is often underestimated and should be considered more often when explaining the difference in results.

Another explanation could be the higher fluctuation of new harvester operators than familiarized one in companies is higher on new harvester operator than on familiarized one. Therefore, data may misrepresent the overall performance to some degree.

In this analysis intra-daily fluctuations and the impact of shift work is not considered. These two factors may result in fatigue and can have an important influence on the individual performance as stated by Nicholls et al. (2004): "[…] operators fatigue will highest towards the end of the working week". This factor could be eliminated by increasing the number of data. Another aspect can be the weather. In winter, the operator has less daylight to work with and there are also significant differences from snow-reflection versus no snow.

The different systems - first and second thinning - can also influence the productivity. Kärhä et al. (2004) found that: "The differences in the operators' skill levels were especially emphasized in dense, first thinning stands". This could not be observed in this study as the information was not available for most of the stands. (We assume that this should have only an influence on the distance between performance levels and not on the ranking. As Ranta (2004) states: "An effective driver can operate efficiently in all phases of the work cycle."

A significant correlation between the performance level and the repair time could not be detected in this study. This is in conflict with the results from Kirk et al. (1997). The explanation could come from the way the data were analysed. The focus of this study is the operator and rather than the different stages of the learning curves as described by Kirk et al. (1997).

In the future more tasks performed by the harvester operator will be automated, such as boom tip and information collection. Gellerstedt (2002) pointed out: „[…] automation involves a risk of creating a boring job and reducing the operator's alertness." The boredom may decrease the performance over a long time more than the automation increase the performance. A lot of further research is suggested for this field.

The harvester system also has a big influence on the productivity. To eliminate most of the influence and better quantify others over a longer period, more detailed research is needed. One important research aspect could involve a compatible database including a wide range of information on harvester operations to provide a better tool to represent a wide range of operators. Better prediction of time consumption and cost would also be possible.

The differences between the operators are huge and the training phase can be quite extensive. However, once you have good operators – keep them. They are your most valuable assets.

5. Acknowledgements

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