# Production Equations for Tower Yarders in Austria

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**ABSTRACT**

Cable yarding has been used for many years in mountainous forests in central European countries. Tower yarders are common cable yarding systems in Austria. The goal of this study was to develop a general time prediction model for two kinds of tower yarders used in Austria. The multiple regression method was applied. The average production rate was 9.30 $m^3/PSH_0$ with a cost of US$25.48/$m^3$. The results also showed that the production rate for downhill yarding was less than uphill yarding using the Syncrofalke tower yarder. The developed time production models can help forest engineers estimate production of tower yarders in similar logging operations.

**Keywords:** *logging, cable yarding, model, production, cost, tower yarder, yarding distance, whole tree system, uphill yarding, downhill yarding*

## Introduction

Planning for cable yarding systems takes more time than for ground-based systems. Once in place, however, the production rate on steep slopes is comparable to ground-based systems. Most operations using cable yarders are feasible when operating in a high-product-yield stand and when factors affecting production have been carefully evaluated. Cable yarding also has the advantage of minimizing the impact on environmentally sensitive areas, especially when complying with best management practices (BMP) and other forest practice regulations (Huyler and LeDoux 1997).

The cost and production of cable yarding systems has been studied by a number of researchers. The results of such studies are useful for operational planning, assessment of machinery performance, financial control, and increases in the efficiency of timber extraction using cable systems. The productivity of a specific cable yarding system depends on a number of factors, such as tree volume, yarding distance, lateral yarding distance, slope, yarder type, working system, silvicultural treatment, felling method, and learning curve effect of the crew (De Labor 1993, Howard and Coultish 1993, Kellog et al. 1996, Huyler and LeDoux 1997, McNeel and Dodd 1997, Visser and Stampfer 1998, Heinimann et al. 2001, Torgensen 2002, Hartley 2003, Stampfer and Steinmueller 2004, Cavalli et al. 2004, Neri et al. 2008).

Some researchers have studied productivity of cable systems in Austria (Loschek 2004, Stampfer and Steinmueller 2004, Viertler 2003, Svaton 2000, Limbeck-Lilienau 2002, Stampfer et al. 2003, Proell 2000, Visser and Stampfer 1998, Toplitsch 1999). Stampfer et al. (2006) also developed a cable corridor installation time model for Austrian tower yarders. Heinimann et al. (1998) presented a model to predict productivity for harvester-cable yarder systems in thinning operations in terrain with a moderate slope of 15 to 25 percent.

Tower yarders combined with motor-manual felling are widely used in Austrian logging in steep terrains. Therefore, a general yarding time prediction model based on more data from different yarding sites can be useful for the planners. Unlike the study of Heinimann et al. (1998) which studied a harvester-cable yarding system, this study investigated whole tree yarding by modern tower yarders where trees were felled and topped motor manually.

Stampfer et al. (2003) presented the productivity models for Syncrofalke and Wanderfalke tower yarders in southern and northern Austria for uphill yarding. Limbeck-Lilienau (2002) presented a model to predict productivity using variables such as tree volume and harvesting time in northern Austria. The goal of this study was to develop a general combined model based on the collected data of the previously mentioned studies. This general model will include yarder type as a dummy variable to make the model more flexible for logging planning.

For the Syncrofalke tower yarder, both databases were merged to develop an appropriate model for predicting yarding time. Limbeck-Lilienau's model (2002) did not include yarding distance and extraction direction. In this paper a downhill yarding time equation prediction for the Syncrofalke tower yarder is also presented.

The equations are for delay-free yarding time and do not include time for set-up and take-down. The general models were verified using witness samples so that these equations could be applied for logging operations with the same variations within the range of variables of the models. These models can be helpful in logging planning at different harvesting sites in Austria if

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the particular yarder model that is to be used is not known in advance.

## Study Method

### Study Sites

The first site studied a Wanderfalke tower yarder in Privatstiftung Hempel in Etmissl of Steirmark in southern Austria (**Table 1**), and uphill yarding was timed for six cableways (Stampfer et al. 2003). The second site was located in Gruenau in Almtal in northern Austria where a Synkcrofalke tower yarder was used for uphill yarding. The third site, located in Steyr and Gmunden in northern Austria, was harvested using the Syncrofalke tower yarder in downhill and uphill yarding.

### Work Organization

At the first study site, the Wanderfalke tower yarder (**Table 2**) was used in uphill and downhill yarding. This tower yarder is based on a truck and combined with a Woody 50 processor. The trees were felled and topped motor manually and extracted to the landing. At the landing, the trees were delimbed, bucked, and stacked by a processor. The working team included a chainsaw operator, choker setter, and yarder operator.

**Table 1.** ~ *Study site description.*

| | First site | Second site | Third site |
|---|---|---|---|
| Yarding distance (m) | 98 to 198 | 98 to 198 | 180 to 440 |
| DBH (cm) | 16.1 to 26.8 | 28.5 to 32.4 | 28.9 to 33.0 |
| Tree volume ($m^3$) | 0.20 to 0.64 | 0.67 to 1.02 | 0.67 to 1.06 |
| Slope of cable way (%) | 37 to 77 | 31 to 49 | 32 to 60 |
| Stand composition | Fir | Fir | Fir-Larch and Beech |
| Stand density (n/ha) | 872 to 2,536 | 700 | 551 to 745 |

**Table 2.** ~ *Technical description of the Wanderfalke tower yarder.*

| | | |
|---|---|---|
| Total system | Weight (kg) | 24000 |
| Truck OEAF | Power (kW) | 243 |
| Boom V-Kran 20.88 | Length (m) | 9 |
| | Max. moment (kNm) | 192 |
| Wanderfalke | Max. tractive force (kg) | 1500 |
| | Max. cable speed (m/s) | 6 |
| | Height of tower (m) | 9 |
| | Diameter of drum core (mm) | 508 |
| | Skyline diameter (mm) | 16 |
| | Mainline diameter (mm) | 10 |
| | Tail rope diameter (mm) | 6 |
| Processor Woody 50 | Weight including rotator (kg) | 750 |
| | Max. cutting diameter (cm) | 55 |
| | Max. delimbing diameter (cm) | 50 |
| | Max. gripper opening (cm) | 95 |
| | Feed rate speed (m/s) | 0 to 3 |
| | Max. draw force (kN) | 28 |
| Carriage Sherpa-U-1.5 ton | Payload (kN) | 15 |
| | Weight (kg) | 250 |

The Synkrofalke tower yarder (**Table 3**) was studied on the second and third sites. This yarder was combined with a Wolf 50 B processor. The working team consisted of two people. The chainsaw operator was responsible for felling, topping, and choker setting. The yarder operator extracted the whole trees to the landing. The yarder operator was free to start delimbing and bucking the tree using the processor when the carriage was at the landing and during the out-haul element of yarding.

### Time Study

The total working cycle was timed using handheld microcomputers. The working cycle included outhaul, mainline release, choker setting, lifting the load, inhaul, and load release at the landing. This study did not separate the time of each element of the working cycle. It was assumed that free delay yarding time is a function of yarding distance, lateral yarding distance, tree volume, harvest intensity, stand density, slope, and yarder type. These variables were recorded for each timed working cycle. Before yarding operation, all of the study trails were marked on the stands. The lateral yarding distance of 15 m was marked on the trees at both sides of cable ways. All of the trees with a diameter at breast height (DBH) larger than 10 cm in the corridor were measured and marked with a number. Tree volume was evaluated using the formulation developed by Pollanschuetz (1974) based on DBH, species, and height. The age of the stand was determined based on the stand detail maps. Considering extracted trees per yarding cycle, stand density and harvest intensity were determined (Limbeck-Lilienau 2002). Load volume was calculated by multiplying the average tree volume by the number of trees per turn.

### Statistical Analysis

The databases from two earlier time studies are presented in **Table 4**. To develop a general model, a new dummy variable was

**Table 3.** ~ *Technical description of the Syncrofalke tower yarder.*

| | | |
|---|---|---|
| Total system | Weight (kg) | 24000 |
| Truck OEAF | Power (kW) | 235 |
| Boom V-Kran 20.88 | Length (m) | 8.97 |
| | Max. moment (kNm) | 232 |
| Syncrofalke | Max. tractive force (kg) | 3000 |
| | Max. cable speed (m/s) | 9.2 |
| | Height of tower (m) | 10.4 |
| | Diameter of drum core (mm) | 1000 |
| | Skyline diameter (mm) | 18 |
| | Mainline diameter (mm) | 11 |
| | Tail rope diameter (mm) | 8.5 |
| Processor Wolf 50 B | Weight including rotator (kg) | 830 |
| | Max. cutting diameter (cm) | 50 |
| | Max. delimbing diameter (cm) | 40 |
| | Max. gripper opening (cm) | 85 |
| | Feed rate speed (m/s) | 1.8 |
| | Max. draw force (kN) | 45 |
| Carriage Sherpa-U-3 ton | Payload (kN) | 30 |
| | Weight (kg) | 380 |

used for yarder type. The corresponding values for Wanderfalke and Syncrofalke were 1 and 0, respectively.

The yarding time per cycle is assumed to be a function of the previously mentioned variables. The stepwise regression method was applied to develop the model in SPSS 15. This modeling procedure tests the significance of the impact caused by each variable on residual mean squares (RMS) of the model. The variable with significant impact on RMS was included in the equation. The tolerance and variance inflation factor of the variables were determined to examine the collinearity among the variables.

The validity of the models was verified. The confidence intervals for each coefficient of the models were computed using the software. If the actual times of witness sample were within the confidence intervals, the model was statistically valid.

## Results

### Whole Tree Yarding Using Tower Yarders (General Model)

#### *Production*

By dividing mean load volume to mean delay-free yarding time, the production rate was calculated as 9.30 $m^3/PSH_0$ (productive system hour) considering both uphill and downhill yarding. The average productivity of Wanderfalke and Syncrofalke tower yarders were 7.03 $m^3/PSH_0$ and 10.7 $m^3/PSH_0$, respectively, based on the site characteristics of the operation sites.

#### *Yarding costs*

The machine cost for the Syncrofalke yarder with Processor Wolf 50 B was \$180.22/$PSH_0$[1] (including operator) and the labor cost for two workers was \$93.45/$PSH_0$, so total cost was estimated to be \$273.67/$PSH_0$ based on information from the Mayr-Melnhof forest company. Considering the production of 10.7 $m^3/PSH_0$, the yarding cost averaged \$25.58/$m^3$.

For the Wanderfalke tower yarder with the Woody 50 processor, the machine cost and labor cost were \$153.52/$PSH_0$ and \$46.72/$PSH_0$, respectively. Therefore, the machine rate was \$200.24/$PSH_0$. Based on the production rate of 7.03 $m^3/PSH_0$, yarding cost was estimated about \$28.48/$m^3$.

The machine rate for both tower yarders averaged \$236.95/$PSH_0$. This rate yielded the mean yarding cost of \$25.48/$m^3$.

### Yarding Time Prediction Model for the Syncrofalke and Wanderfalke Tower Yarders

The mean productivity of the Wanderfalke and Syncrofalke tower yarders based on the combined data bases were 7.03 $m^3/PSH_0$ and 10.7 $m^3/PSH_0$, respectively. A comparison of the means showed that the average productivity of the two yarder types were significantly different at $\alpha = 0.05$. Yarder type was used in modeling as a dummy variable. **Table 5** illustrates the study layout based on the available databases.

[1] Dollar values are U.S. dollars.

**Table 4.** ~ *Databases for tower yarders.*

| | Number of working cycles | |
|---|---|---|
| Researcher | Syncrofalke | Wanderfalke |
| Stampfer et al. 2003 | 207 | 596 |
| Limbeck-Lilienau 2002 | 752 | -- |

**Table 5.** ~ *Study layout and number of observations.*

| | Syncrofalke tower yarder | Wanderfalke tower yarder |
|---|---|---|
| Downhill yarding | 540 | -- |
| Uphill yarding | 418 | 596 |

Based on **Table 5**, the data for both yarders are not balanced for different yarding directions. The univariate analysis of variance (ANOVA) used this fixed factor and covariates including the other variables (yarding distance, lateral yarding distance, stand density, harvest intensity, slope, tree volume, and yarder type). This analysis showed a non-significant impact of fixed factor.

The other variable as "factor" was defined for downhill yarding by Syncrofalke (value of 0), uphill yarding by Wanderfalke (value of 1), and uphill yarding by Syncrofalke (value of 2) to investigate the impact of yarding direction under unbalanced conditions.

The stepwise regression procedure yielded the following prediction model:

$$\begin{gathered} T\ (\text{min/cycle}) = 0.005 \times \text{Yarding distance (m)} + 0.092 \times \\ \text{Lateral yarding distance (m)} + 0.601 \times \text{Tree volume}^{-0.3}\ (\text{m}^3) + \\ 0.018 \times \text{Harvest intensity (\%)} + 0.038 \times \text{Slope (\%)} + \\ 1.125 \times \text{Yarder type} \end{gathered}$$

$R^2 = 0.90$, adjusted $R^2 = 0.899$, number of observations = 1,554.

The value for the Wanderfalke yarder was yarder type = 1 and for the Syncrofalke yarder the yarder type = 0. The multiple correlation coefficient of 0.90 was interpreted as 90 percent of total variability was explained by the regression equation. The "factor" variable (presenting yarding direction) and stand density could not be significantly included in the equation. From this model, the larger the tree the shorter the yarding time.

Increasing other variables will increase yarding time. Based on the variance inflation factor (VIF) values of variables used in the general model, there was not important collinearity among the variables (**Table 6**). Furthermore the interaction between yarder type and tree volume was not significant.

The significant level of ANOVA (**Table 7**) shows that the model makes sense at $\alpha = 0.05$. The validity test using three witness samples confirmed that the model is reliable at a probability level of 5 percent.

### Yarding Time Prediction Model for the Syncrofalke Tower Yarder

The production rate and yarding cost averaged 10.7 $m^3/PSH_0$ and \$25.58/$m^3$, respectively, for the combined databases. Whole tree yarding included both uphill and downhill yarding.

**Table 6.** ~ *Tolerance and VIF values of the variable for the general model.*

| | Collinearity statistics | |
|---|---|---|
| Variable | Tolerance | VIF |
| Slope | 0.067 | 14.886 |
| Yarder type | 0.396 | 2.526 |
| Lateral yarding distance | 0.377 | 2.653 |
| Yarding distance | 0.275 | 3.634 |
| Harvest intensity | 0.169 | 5.925 |
| Tree volume | 0.057 | 17.689 |

**Table 7.** ~ *ANOVA of the yarding time prediction model for both yarders (Syncrofalke and Wanderfalke).*

| Source | Sum of squares | df | Mean squares | F-value | Sig. |
|---|---|---|---|---|---|
| Model | 45731.400 | 7 | 6533.057 | 1986.102 | 0.00 |
| Residuals | 5088.681 | 1547 | 3.289 | | |
| Total | 50820.081 | 1554 | | | |

Yarding time prediction model for Syncrofalke tower yarder:

$$T(\text{min/cycle}) = 0.007 \times \text{Yarding distance (m)} + 0.043 \times \text{Lateral yarding distance (m)} + 1.307 \times \text{Tree volume}^{-0.3}(\text{m}^3) + 0.029 \times \text{Harvest intensity (\%)} + 0.038 \times \text{Slope (\%)}$$

$R^2$ =0.886, adjusted $R^2$ = 0.885, number of observations = 958.

This multiple correlation coefficient of 0.886 suggests that 88.6 percent of total variability can be explained by the regression equation.

Because of the very high VIF value for stand density, this variable was excluded from modeling. **Table 9** presents the VIF values for the parameters used in the Syncrofalke time prediction model.

The significant level of this ANOVA (**Table 10**) shows that the model is significant at $\alpha = 0.05$.

The validity test using two witness samples confirmed that the model was valid at a probability level of 5 percent.

## Uphill and Downhill Yarding for Syncrofalke Tower Yarder

The uphill yarding equations were based on the combined set of two cableways from Limbeck-Lilienau (2002). The downhill equations were based on four cableways from the database of Limbeck-Lilienau using the Syncrofalke tower yarder. There was a significant difference between production rates in downhill and uphill yarding. The production rate in uphill yarding averaged at 11.54 $m^3/PSH_0$ (cost of \$23.71/$m^3$). For downhill yarding, the production of 8.25 $m^3/PSH_0$ (cost of \$33.16/$m^3$) was evaluated. The model for uphill yarding was developed but yarding distance did not enter into the model significantly because of less variation in the data for this important variable; therefore, further study should be conducted to develop an appropriate model.

Downhill yarding time prediction model for Syncrofalke tower yarder:

**Table 8.** ~ *Descriptive statistics for the parameters of the general model.*

| Parameter | Max. | Mean | Min. |
|---|---|---|---|
| Cycle time (min.) | 13.89 | 5.39 | 1.55 |
| Productivity ($m^3$/h) | 64.6 | 9.30 | 0.69 |
| Yarding distance (m) | 300 | 101.11 | 1.55 |
| Lateral yarding distance (m) | 38 | 8 | 0 |
| Number of trees per turn | 5 | 1.78 | 1 |
| Load volume ($m^3$) | 3.457 | 0.78 | 0.07 |
| Tree volume ($m^3$) | 3.457 | 0.53 | 0.06 |
| Stand density (n/ha) | 2,862.45 | 1,025.62 | 0 |
| Slope (%) | 77 | 50.53 | 6 |
| Yarder type | 1 | 0.62 | 0 |
| Harvest intensity (%) | 95.3 | 36.5 | 0 |

**Table 9.** ~ *Tolerance and VIF values for the variables used in the yarding time prediction model for the Syncrofalke tower yarder.*

| | Collinearity statistics | |
|---|---|---|
| Variable | Tolerance | VIF |
| Tree volume | 0.066 | 15.100 |
| Slope | 0.080 | 12.517 |
| Harvest intensity | 0.190 | 5.262 |
| Yarding distance | 0.274 | 3.650 |
| Lateral yarding distance | 0.348 | 2.870 |

**Table 10.** ~ *ANOVA of the yarding time prediction model for the Syncrofalke tower yarder.*

| Source | Sum of squares | df | Mean squares | F-value | Sig. |
|---|---|---|---|---|---|
| Model | 28068.652 | 5 | 5613.730 | 1478.779 | 0.000 |
| Residuals | 3617.771 | 953 | 3.796 | | |
| Total | 31686.422 | 958 | | | |

$$T(\text{min/cycle}) = 0.009 \times \text{Yarding distance (m)} + 0.038 \times \text{Lateral yarding distance (m)} + 1.491 \times \text{Tree volume}^{-0.3}(\text{m}^3) + 0.034 \times \text{Harvest intensity (\%)} + 0.025 \times \text{Slope (\%)}$$

$R^2$ = 0.889, adjusted $R^2$ = 0.888, number of observations = 541.

The multiple correlation coefficient of 0.889 is interpreted as 88.9 percent of the total variability which can be explained by this model. Stand density for this model was not used due to its high VIF. **Table 11** presents the collinearity statistics of downhill yarding model. According to the ANOVA (**Table 12**) the model is significant at $\alpha$ = 0.05. Using two witness samples, the validity test confirmed reliability of this equation.

## Conclusions

The cycle-time equations for Austrian tower yarders provides forest engineers a management tool for use in estimating production levels and cost of production in similar logging operations. The general yarding time prediction model can be used for both Syncrofalke and Wanderfalke tower yarders including a new variable of yarder type. The new time model for Syncrofalke yarder consists of significant variables such as yarding distance, lateral yarding distance, harvest intensity, stand

**Table 11.** ~ *Tolerance and VIF values for the variables used in the downhill yarding time predicting model for the Syncrofalke tower yarder*

| Variable | Collinearity statistics Tolerance | VIF |
|---|---|---|
| Tree volume | 0.078 | 12.773 |
| Slope | 0.071 | 14.021 |
| Harvest intensity | 0.111 | 9.008 |
| Yarding distance | 0.281 | 3.564 |
| Lateral yarding distance | 0.394 | 2.538 |

**Table 12.** ~ *ANOVA of the downhill yarding time predicting model for the Syncrofalke tower yarder.*

| Source | Sum of squares | df | Mean squares | F-value | Sig. |
|---|---|---|---|---|---|
| Model | 16302.125 | 5 | 3260.425 | 61.827 | 0.000 |
| Residuals | 2027.772 | 536 | 3.783 | | |
| Total | 18329.897 | 541 | | | |

density, and slope. Compared to previous models, the new one is statistically more utilizable.

The production rate for downhill yarding was less than for uphill yarding using the Syncrofalke yarder. This suggests that uphill yarding is more productive than downhill yarding. This difference may be due to not having to use brakes for uphill yarding as needed in downhill yarding.

Future research is needed to study downhill yarding using the Wanderfalke tower yarder in different logging sites to get higher variance in yarding distance for uphill yarding with the Syncrofalke yarder so that a valid model can be constructed. Also future research could be conducted on developing general models for cable yarding in the cut-to-length method.

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