Ecological aspect of mobile systems operated in terrain conditions

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ABSTRACT: In this paper is evaluated an optimal constructional and operating performance of the mobil terrain system, that works in forest ecosystems from point of view of volume of processed biomass and total amount of logging transport erosion. A monitored terrain system, working in forestry, is considered as a production system, with its material and energy flow. The determination value, that optimizes the production system, is the operating and constructional performance. In this paper is evaluated the amount erosion in dependence of cutting mass, by means of mathematics and from system point of view. The conditions for the mobile terrain system work, that insure optimal, i.e. minimal value of erosion will be determined. The theoretical results are verified. The optimal values of soil erosion are determined by experimental measurements. The principles of the paper are based on theses of ecological synthesis that determine coupling between dissipative energy of a production system and its ecological cleanliness of work.

Keywords: mobile terrain system; forest ecosystem; mathematical simulation

The logging transport and subsequent water erosion cause devastion of forest ecosystems (ŠACH 1986). It thereby suffer not only productive, but also unproductive forest functions, including contamination of surface water sources. The devastation of forest soils is problem mainly in air-polluted regions by dieback of forest stands, as well as their subsequent cutting (SKÝPALA 1987).

The exploitation of transport technique, technique for mechanical preparation of soil, mainly in upland of air-polluted regions results to increased devastation of soil surface of forest ecosystems (ŠACH 1986). The erosion processes then conduct not only to the decreasing of forest soil, but also to it degradation and degradation of water relations of soil (HOLÝ 1988).

The preventive wood-technical measurements, serve us to decrease damages caused by erosion (KUBELKA pers. commun.). They consist of choice of ecological canny technologies (JANEČEK 1992) by using a suitable technique with rational performance. This paper discusses possibilities of its determining.

The verification is carried out by experimental monitoring of logging transport erosion caused by skidding units TERRI 20-20 and TERRI 20-40.

The task of the paper is also to confirm the known theses of ecological synthesis (DUVIGNEAUD 1980). The dissipative energy produced by a production system (in our case it is a mobile system working in forestry) is a rate of ecological cleanliness of the system's work.

SPECIFICATION OF FACTORS THAT AFFECT THE LOGGING TRANSPORT EROSION

With the analysis of the logging transport technique with various performance we can ascertain, that this performance is commensurable to the amount of damages caused by logging transport erosion.

The factors that affect the specific consumption of energy and material:

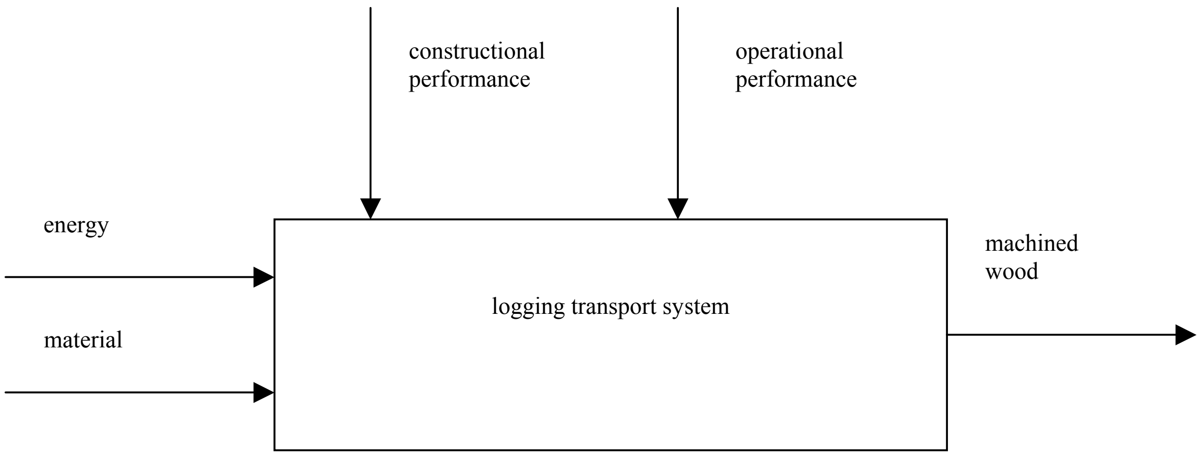
a) The increase of constructional performance does not respond directly to dimensions of parts of logging transport and afforestation systems, which exercise an influence on energy, material and working components.
b) The change of parts of these systems which demand a lot of investments is not directly commensurable with performance change.
c) The changes of material flow due to changes of system's performance do not always actuate to change of energy and material demands and consequently not even to total amount of damages caused by erosion.

The possible increases of the constructional performance of forest systems:

a) increase an interaction space for material flow (chopping, cutting area, etc.) or increase the maximal work performance,
b) increase the cross sections within roads on which a material is transported.

OPTIMAL MODE OF LOGGING TRANSPORT SYSTEM FROM POINT OF VIEW OF RELATIONSHIP BETWEEN EROSION AND UNIT OF PERFORMANCE

During productional process of logging transport systems energy and material are transformed. The transformation of energy and material results in final product – machined wood (Fig. 1).



A regulation of intensity of logging transport work is carry out by regulators, which specified the constructional and operational performance. At the same time, during work of these systems the logging transport erosion is rising. It depends on intensity of whole process and it is a result of the loss energies which rise during this process.

Value of logging transport erosion in course of the production process as a result of energy transformation is given by formula:

$$M_{EE} = \frac{m_E \,.\, Q_E}{\eta_{CE}\,(W_k,\, W_p)} \,.\, S_E \qquad \text{(kg)} \qquad (1)$$

where: M_{EE} – amount of logging transport erosion rised during work of logging transport system as a result of energy transformations (kg),
m_E – amount of energy source (naphtha, gasoline, etc.) needed for production (kg),
W_p – operational performance of system (m^3/s),
W_k – constructional performance of system (m^3/s),
S_E – specific inherent (supplied) energy that rises as a result of energy transformations during production process (kg/J),
Q_E – specific energy of energy source (J/kg),
η_{CE} – efficiency of energy transformations into final product in dependence on constructional and operational performance (–).

The total amount of production carried out by performed logging transport system with transformation of given amount of energy is expressed by the following formula:

$$W_C = \frac{m_E \,.\, Q_E}{Q_V \eta_{CE}\,(W_k,\, W_p)} \qquad (\text{m}^3) \qquad (2)$$

where: W_C – total amount of production of a system, produced as a result of energy transformation (m^3),
Q_V – specific production energy, that is needed to supply to the logging transport system per unit of production (J/m^3).

If we consider that Q_E, S_E, η_E are constants for time of the analysis, we can express the time derivations of formula (1) as follow:

$$\frac{\partial M_{EE}}{\partial t} = \frac{\frac{\partial m_E}{\partial t} \cdot Q_E}{\eta_{CE}\,(W_k,\, W_p)} \,.\, S_E \qquad \text{(kg/s)} \qquad (3)$$

where: t – time (s),
$\frac{\partial M_{EE}}{\partial t}$ – amount of logging-transport erosion arisen per time unit due to energy transformation (kg/s),
$\frac{\partial m_E}{\partial t}$ – energy carrier amount supplied per unit of time (kg/s).

$$\frac{\partial M_{EEM}}{\partial t} = \frac{\frac{\partial m_E}{\partial t} \cdot Q_E}{\eta_{CE}\,(W_k,\, W_p)} \,.\, S_E \qquad \text{(kg/s)} \qquad (4)$$

where: $\frac{\partial M_{EEM}}{\partial t}$ – total erosion produced by system per unit of time (kg/s).

$$Q = \frac{\partial M_{EEM}}{\partial t} \,.\, \frac{1}{W_C\,(W_k,\, W_p)} = \left[\frac{\frac{\partial m_E}{\partial t} \cdot Q_E \,.\, S_E}{\eta_{CE}\,(W_k,\, W_p)}\right] \,.$$

$$. \frac{1}{W_C\,(W_k,\, W_p)} \qquad (5)$$

where: Q – specific erosion referred to the unit of production.

To obtain an extreme of the function of specific logging transport erosion, referred to the unit of volume of machined mass in function of constructional and operational performance the following conditions have to be fulfilled:

$$\frac{\partial^2 M_{EEM}\,(W_k,\, W_p)}{\partial t \,.\, \partial W_k} = 0 \qquad (\text{kg/m}^3) \qquad (6)$$

$$\frac{\partial^2 M_{EEM}}{\partial t \,.\, \partial W_P} = 0 \qquad (\text{kg/m}^3) \qquad (7)$$

Considering the former equations the following formulas were obtained:

$$\frac{\partial f_E\,(W_k,\, W_p)}{\partial W_k} - \frac{f_E}{\eta_{CE}\,(W_k,\, W_p)} \,.\, \frac{\partial \eta_C\,(W_k,\, W_p)}{\partial W_k} - \frac{f_E}{W_C\,(W_k,\, W_p)} \,.$$

$$. \frac{\partial W_C\,(W_k,\, W_p)}{\partial W_k} = 0 \qquad (\text{kg/m}^3) \qquad (8)$$

$$\frac{\partial f_E (W_k, W_p)}{\partial W_p} - \frac{f_E}{\eta_{CE} (W_k, W_p)} \cdot \frac{\partial \eta_C (W_k, W_p)}{\partial W_p} - \frac{f_E}{W_C (W_k, W_p)} \cdot$$

$$\cdot \frac{\partial W_C (W_k, W_p)}{\partial W_k} = 0 \qquad \text{(kg/m}^3\text{)} \qquad (9)$$

$$f_E = \frac{\partial m_E}{\partial t} \cdot Q_E \cdot S_E (W_k, W_P) \ ...$$

flow of erosion caused by transformation of energy in production process.

GENERAL ANALYSIS

The analysis of formulas which are needed for determining of amount of logging transport erosion per unit of production of transport system gave the following conditions (JANEČEK 1991):

$\frac{\partial \eta_{CE} (W_p)}{\partial W_P} > 0$ valid for area of lower values of operational performance W_P (10)

$\frac{\partial \eta_{CE} (W_p)}{\partial W_P} < 0$ valid for area of higher values of operational performance W_P (11)

$\frac{\partial \eta_{CE} (W_k)}{\partial W_k} > 0$ valid for area of lower values of constructional performance W_k (12)

$\frac{\partial \eta_{CE} (W_k)}{\partial W_k} < 0$ valid for area of higher values of constructional performance W_k (13)

Further useful relations:

$f_E > 0$ physical technical parameter (kg/s) (14)

$\eta_{CE} > 0$ physical technical parameter (–) (15)

$\frac{\partial W_C}{\partial W_P} > 0$ performance of production system ascend in function of operational performance W_P (16)

$\frac{\partial W_C}{\partial W_k} > 0$ performance of production system ascend in function of constructional performance W_k (17)

Using equations (8) and (9) the following inequalities are obtained:

$$\frac{\partial f_E (W_k, W_p)}{\partial W_k} - \frac{f_E}{\eta_{CE} (W_k, W_p)} \cdot \frac{\partial \eta_C (W_k, W_p)}{\partial W_k} - \frac{f_E}{W_C (W_k, W_p)} \cdot$$

$$\cdot \frac{\partial W_C (W_k, W_p)}{\partial W_k} > 0 \qquad \text{(kg/m}^3\text{)} \qquad (18)$$

… valid for area of higher values of constructional performance

$$\frac{\partial f_E (W_k, W_p)}{\partial W_P} - \frac{f_E}{\eta_{CE} (W_k, W_p)} \cdot \frac{\partial \eta_C (W_k, W_p)}{\partial W_P} - \frac{f_E}{W_C (W_k, W_p)} \cdot$$

$$\cdot \frac{\partial W_C (W_k, W_p)}{\partial W_k} < 0 \qquad \text{(kg/m}^3\text{)} \qquad (19)$$

… valid for area of lower values of constructional performance.

Similar analysis leads to relation that specifies a behaviour of the function of specific erosion concerning parametres that specify the operational performance.

Equation (18) shows that parametres W_k, W_p affect the flow of erosion (logging transport erosion) as well as the inherent flow and production process, moreover they affect also the efficiency of the energy transformation to final products.

The quantitative relation (18) validates general thesis by DUVIGNEAUD (1980):

The amount of dissipative energy is the rate of ecological cleanliness (logging transport erosion) of work of a mobile terrain system.

This thesis is then validated by the above-mentioned analysis of work of mobile terrain systems in dependence on their intensity of work.

VERIFICATION OF THE MATHEMATICAL MODEL

The above mentioned analysis was used as a basis for evaluation experiments. The mathematical model of forest production systems allows optimization of their main constructional and operational parameters from point of view of ecological needs (Figs. 2 and 3). Physical models were used for the systems – working machine in logging, afforestation and transport activities. It was found that the optimization of the system performance can lead to decreases of the logging transport erosion about 5–15%.

The locality, where the verification was carried out, was specified by following significant attributes.

Characteristics of natural conditions:

– altitude	900 m,
– exposure	NW,
– terrain inclination	11–20%,
– average soil condition during monitoring	humidity –30%,
– predisposition to erosion	easier erodable,
– ground bearing capacity	relatively bearing (50–200 MPa),
– terrain carriageability	obstacles smaller than 50 cm in distance more than 5 m,
– brokenness of terrain	middle range (configuration coefficient 0.25–0.49),
– soil condition	middle weedy (cover 26 to 50% of area).

Characteristics of natural intervention
– salvage cutting, group of trees.

Tree species
– conifers.

Mean tree volume 0.9 m^3 (form of expression of volume or forest trees stands).

Force of intervention 12%.

Technological characterization of work places:
- roadside – out of forest stand border in distance of 50 m,
- logging method – wood assortments of standard lengths of 2 m.

Technical characteristics of mobile terrain systems:

TERRI 20-20: engine – Kubota, type DH 850-B, four-stroke, diesel,
power – 17 kW at 3,600 rpms,
dimensions – length 6,500 mm, width 1,460 mm, height 2,350 mm,
weight – 3,390 kg,
transport weight – 1,690 kg,
scope of hydraulic crane – 4.2 m.

TERRI 20-40: engine – Kubota, type D 1105, four-stroke, diesel,
power-output – 17.6 kW at 3,000 rpms,
dimensions – length 6,500 mm, width 1,470 mm, height 2,250 mm,
weight – 4,950 kg,
transport weight – 2,960 kg,
scope of hydraulic crane – 7 m.

Damages of forest soil:

Procedure of measuring and evaluating.

A measurement of planary damage was carried out. The measurement was carried out by measuring-tape with digital display. A damage of soil surface was plotted in scale 1:100. Similarly, by measuring-tape were carried out the measurements of skidding trajectories "l_i". Areas of trajectory damages was read by digital planimeter. The volumes of skidded wood was summarized by volumes "V_i" per time unit of one month.

By calculation were determined the coeficients of damage which indicate the damage in area 1 m^2 per 1 m^3 of transported wood and 1 m of length of wood transport.

The calculation of relative damage was carried out by formula:

$$K = \frac{\sum_i F_i}{\sum_i l_i V_i} \quad (m^2/m/m^3) \qquad (20)$$

where: K – coefficient of relative damage (m^2/m/m^3),
$\sum_i F_i$ – total damaged area (m^2),
$\sum_i l_i$ – total traveled length during wood transport (m),
$\sum_i V_i$ – total volume of skidded wood (m^3).

Results in graphical form

Skidding unit TERRI 20-20 is designed for total month capacity ca. 200–400 m^3. In conditions at which the measurements were carried out the optimal operational performance (Fig. 2) was at level of ca. 400 m^3.

It is the upper border of operational performance which is referred by manufacturer. Considering the criterion of logging transport erosion there is a need to operate the unit TERRI 20-20 on this value of the optimal performance.

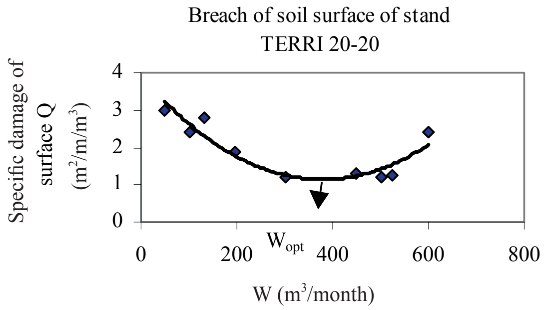


Fig. 2. Dependence between specific amount of damages and operational performance TERRI 20-20

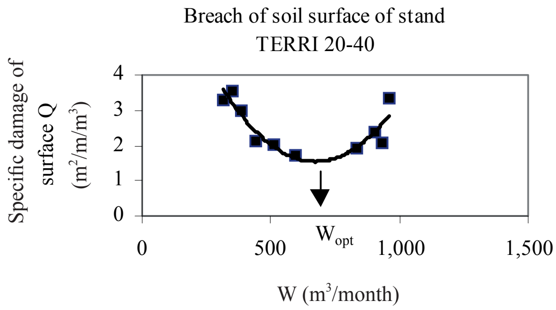


Fig. 3. Dependence between specific amount of damages and operational performance TERRI 20-40

In case of increasing or decreasing of the performance by 5–10% the specific erosion will increase by 30–40%. The similar results were obtained in case of experimental measurements with the unit TERRI 20-40.

CONCLUSION

By mathematical analysis it was found that logging transport erosion rising during work of the system has minimum value in the work mode, which can be characterized by optimal operational and constructional performance. This conclusion was verified by experimental observation of the skidding units TERRI 20-20 and TERRI 20-40. When the optimal values of work of above mentioned systems are changed by 5–10%, there will occur the growth of erosion by 15–30%. Because of it there is need of fairly consideration of the localities of their employment and intesity of work, that are given by their operational performance.

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Received for publication June 6, 2003
Accepted after corrections July 31, 2003

Racionalizace mobilního terénního systému z hlediska ekologické čistoty práce

ABSTRAKT: V příspěvku se z pohledu výše zpracované biomasy a celkové výše těžebně dopravní eroze hodnotí optimální konstrukční a provozní výkonnost mobilního terénního systému pracujícího v lesním hospodářství. Sledovaný terénní systém pracující v lesním ekosystému chápeme jako systém výrobní, do kterého vstupuje energetický či materiálový tok. Řídící veličinou, která optimalizuje výrobní režim pracovního systému, je provozní a konstrukční výkonnost. V článku se analyzuje množství eroze v závislosti na vytěžené hmotě systémově a matematicky. Stanoví se podmínky pro práci mobilního terénního systému, pomocí kterých se dosáhne optimální, tj. minimální množství těžebně dopravní eroze, vztažené na jednotku objemu zpracovaného dřeva. Teoretické vývody jsou experimentálně verifikované sledováním vyvážecích souprav TERRI 20-20 a TERRI 20-40. Monitorováním vyvážecích souprav bylo zjištěno, že změní-li se výkonnost výrobních systémů TERRI 20-20 a TERRI 20-40 o 5–10 %, nastává přírůst měrné eroze o 15–30 %. Je proto důležité důsledně zvážit čas a místo nasazení jejich práce, které je dané jejich provozní výkonností. Teoretický rozbor a provedený experiment potvrzuje obecně platnou tezi (DUVIGNEAUD 1980). Množství disipativní energie provázející výrobní proces práce mobilního terénního systému je mírou ekologické čistoty (těžebně dopravní eroze) práce mobilního terénního systému. Minimalizací této disipativní energie je možné zajistit optimální režim práce mobilního terénního systému z hlediska daného kritéria těžebně dopravní eroze.

Klíčová slova: mobilní terénní systém; lesní ekosystém; matematická simulace

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