On the fuzzy integrated assessment – influences of mechanised harvesting operation on forest environment

Lan, Z.

Dept. of Forest Resource Management, P.O.Box 24, FIN-00014
University of Helsinki, Finland, zhangren.lan@helsinki.fi

Abstract

Promoting mechanisation of forest operation results in a more and less unacceptable environmental impact. Due to the increasing environmental concerns during past more than ten years, forest managers are urged to assess the environmental impact of current mechanisation and to solve those problems. From the point view of harvesting timber, it is very important that the optimization of harvesting system should be based on the environmental oriented procedure. In doing so, critical point is how to quantitatively assess the impact of harvesting operation on forest environment during optimising procedure of harvesting system. In this paper, harvesting machine performance indexes are defined as analytical tools of output of harvesting machine or mechanical systems in the way of standardised and aggregated factors. Based on analyzing the environmental consequences of harvesting operations, soil compaction, forest site disturbances and damage to stands are arisen as critical environmental parameters for the purpose of integrated assessment. Further more, in the scope of the theory of fuzzy mathematics, a fuzzy integrated assessment model has been established for assessing environmental consequences in relation with the reasonability and operability of harvesting machine.

Keywords: harvesting operation, harvesting machine performance index, environmental parameters, fuzzy sets, fuzzy integrated assessment model

1 Introduction

In Europe and other developed countries, mechanisation of operation is a rapidly increasing trend in order to increase labour productivity and harvest timber in cost-effective way. At same time, promoting mechanisation of forest operation results in a more and less unacceptable environmental impact, caused either by misuse or by the objective inadequacy of a specific piece of equipment (Spinelli 1994). From the point view of harvesting timber, when setting up the planning of wood procurement forest managers or decision-makers concentrate mainly on the most appropriate mechanical system interaction with harvesting target area in specific given topographical conditions, i.e. methods for the selection of appropriate equipment and techniques, which is an effective procedure of optimising harvesting system in theory and practice. In conventional rules, operability of mechanical systems are always paid close attention under the given conditions. Due to the increasing environmental concerns during past more than ten years, foresters are urged to assess the environmental impact of current mechanisation and to solve those problems.

According to a large amount of literature, environmental consequences of harvesting operation had been worked out elaborately in the relation with the various types of forest machines. Consequently, operability and functionality of machines are greatly improved with the aspects of environment-friendly and ergonomically requirements. However, it is easily ignored and difficultly figured out that the point is, let's say, environment first, and then use of machines and system assessment. From this point of view, a critical point is how to correctly use machines in any given condition so that the minimum damage must be inflicted on the forest environment. In other word, this is other facet to solve problems concerned in opposite way under the environmental orientation. This paper deals with the biological and mechanical system interaction and assessment method on harvesting operation, which tries to figure out the critical parameters on appropriate mechanical system of harvesting timber operation and establish a fuzzy model of mechanical system assessment.

2 Common points to be interrelated between harvesting operations and mechanical systems

Timber harvesting operations, as a systematic behaviour, exist strictly as multiple targets, including not only timber production itself but also socially acceptable state, economical feasibility and environmentally friendly aspects, under which might establish an integrated optimization model of harvesting system based on the environmental assessment on influence of harvesting operations during the commercial timber production rotation. Assessment of environmental consequences on harvesting operation focuses naturally on the man-machine system (mainly involving the skills, scrupulousness, and motivation of the operator) and interaction between machine and forest land.

2.1 Logging patterns and machine size

For the activities of timber harvesting, from first thinning and commercial thinning to the final cutting, different machines and tools are always travelling through the stand. Mechanised operation are always carried out with mall, medium or large size machines. As a system, harvesting operation incorporate different machines fitted to each necessary process. Under the conditions of different logging patterns, harvesting method and operation with different size machines must meet following requirements: ecologically based, management objectives, operationally feasible and socially acceptable. Machine size and its characteristics, to a large extent, plays a determinative role of reducing damage to soil condition and forest stand. The basic parameters to directly bring about the environmental consequences include overall height, length and width defining vehicle gauge which is related with spacing, free height and manoeuvrability between the trees especially in carrying out thinning operation. Theoretically, machine size reflects the working capacity in dimensions, volume and weight which define ground pressure impacts on the soil. In addition, structural properties of the machine determine the extent of environmental consequence dominating concerns of damage to soil and remaining stands.

Defining parameters of machine size incurring environmental risk in a given logging pattern is principally in relation with the vehicle gauge and weight for the management and the execution of the operations , category of engine power and pressure on the soil concerned as well in accordance with biological requirements. According to the presentation of Abeels (1994), for the purposes of classification relating to machine size with small, medium and large type to be fitted with different logging patterns, data about forest equipment might be demonstrated as the relationship between engine power, vehicle gauge and estimated pressure on the ground soil as Table 1.

Table 1. Machine size and correspondence to data about forest equipment.

Machine size	Engine power (Kw)	Width (m)	Total height (m)	Distance between axles (m)	Pressure on the soil (kPa)
1. Ordinary forest tractors					
small	<55	1.1–2.5	<2.8	1.1–2.9	15–100
medium	55–80	2.0–2.6	2.3–2.9	2.3–3.0	20–120
large	>80	2.3–2.9	2.4–3.6	2.6–3.6	20–130
2. Specialised tractors (skidders, haulers, etc.)					
small	<50	2.2–2.5	3.1–3.4	2.9–4.0	50–140
medium	56–80	2.3–2.8	3.2–3.6	3.8–5.2	50–140
large	>80	2.3–2.7	3.3–3.8	4.2–5.3	50–140
3. Combined tractors and trailers (forwarders, processors, etc.					
small	<50	2.0–2.5	2.7–3.3	4.0–4.5	30–120
medium	56–80	2.1–2.5	2.8–3.5	4.5–6.0	30–180
large	>80	–	–	–	30–180

In practice, the pressures on the soil are dependent on the theoretical contact areas given by the manufacturers, which are strongly in relation with the width and numbers of tires or types of tracks of machine.

2.2 Harvesting methods and machine types

Three quarters of the industrial timber crops of the world are harvested with the tree-length and whole-tree skidding systems (Hakkila 1995). In Nordic countries harvesting is completely based on the cut-to-length system. The harvesting methods adopted in given situation determine the types of machinery systems in timber harvesting and the operation mode of the machines by which the environmental factors to be taken into consideration could be specified. Those operation modes of the machines, including processing (i.e. harvesting with harvester, forwarding and feller-bunching), cable yarding, grapple skidding, winching or direct dragging, and loading which means normally that crane loading is a necessary step in the handling of the forest products that implies typical devices mounted on the frame and the machine, can be arranged under categories of different harvesting methods.

In Table 2, environmental consequences of harvesting operation depend on the harvesting method and its operational mode, which can be indicated by the Index of machine performance. And these vary with the logging pattern from thinning to final cutting.

3 Environmental consequences of harvesting operations

Environmental influences of all harvesting operations in the forest stand occur on the ground where it is ineluctable. Especially in the case of first thinning and commercial thinning operations machines have to travel inside the growing stand. It is evident that individual machine or machinery systems in relation with the logging patterns and methods under different working conditions, to a large extent, will exert detrimental impacts on the soil and damage to stands. Different types of machine which operate under the same condition might bring about impacts on the soil and stands depending on the structure and function of machines, for instance, vehicle gauge, stability and trafficability of the equipment and working capacity etc. According to a compilation of the literature (Strokes etc. 1994) and other research concerned, main impacts of harvesting operations on the environment are discussed as following.

3.1 Impacts on the soil

Impacts on the soil involve mainly several detrimental consequences including the logging site disturbance, soil compaction and other consequences of soil. The displacement of forest floor incurs a decrease in water infiltration and drainage, a interruption of pore space continuity with loss of capillarity and allelopathy due to rutting caused by machine passes. On the other hand, compaction of the soil relating to soil

Table 2. Harvesting methods and main environmental consequences and measurement for assessment

Machine	Operation modes	Environ. conseq. (mainly)	Index of performance	Weight of factors
1. Cut-to-length system				
Harvester	Harvesting	– Soil Comp. – Disturbance – Damage to tree	$\mu(u^i)$ * applied	$\sum_{i=1}^{n} a_i$ * applied
Forwarder	Forwarding	– Soil Comp. – Disturbance		
2. Tree-length system				
FellerBuncher	Fellbunching	– Soil Comp. – Disturbance – Damage to tree	applied	applied
Processor	Processing	– Soil Comp. – Disturbance		
Skidder	Skidding	– Soil Comp. – Disturbance – Damage to tree		
3. Whole-tree system				
FellerBuncher	Fellbunching	– Soil Comp. – Disturbance – Damage to tree	applied	applied
Skidder	Skidding	– Soil Comp. – Disturbance – Damage to tree		

* Definition of Index of machine performances and Weight of factors could be seen in section 4 and 5.

bulk density is the effects of machine traffic, which causes a increase in bulk density and soil strength, a decrease of pore space and water infiltration rate and changes in osmotic pressure.

The extent of site disturbance reflects the results derived from the interacting formation of machine-terrain. The rut formation goes further to reflect the extent of site disturbance in relation with the types of tracks and tyres. According to Koger et al. (1984), the dual-tired machines cause much less rutting than the single-tired ones and the trafficability of machine could be greatly improved simultaneously. The research indicated that increasing tyre size would increase bulk density under conditions of the same dynamic load, inflation pressure, and percent travel reduction. And the greatest effect on bulk density is percent travel reduction and the number of machine passes is also the most significant factor influencing rut formation. In addition, where wide and narrow tyres were operating under identical conditions , results showed that wider tyres do decrease the degree of soil compaction and that rut depths increased with the number passes were more for the narrow tyres than for wider tyres. But wider tyres, in fact, caused significantly loss in manoeuvrability. A good planning and precise evaluation is needed when keeping logging costs at acceptable level.

From the point view of machinery systems, in two popular systems of harvesting mechanisation: a feller-buncher, grapple skidder, loader/slasher system and a harvester, forwarder system in thinning operations, the skidder system had significantly more ground disturbance than the forwarder system. In a review (Strokes et al. 1994), the skidder system significantly compacted the soil with surface disturbance, the forwarder system only compacted the soil at the 5-cm depth where the surface was highly disturbed. Further more compared soil disturbance and compaction in different cases of cable logging and ground logging, skidder trails disturbed a large area of the stand, and the greatest compaction occurred in the skyline corridors.

3.2 Biological damage

The damage to stand in harvesting mechanisation comes to the main problem to be paid more attention, which especially occurs in thinning operation. There are mainly three types of damages having directly influences on the stand growth, timber quality or diversity compromising (Abeels 1994): 1) Bark peel off with visible sapwood but no marks in the wood, occasionally incurring harmful infection risk of entrance for insects, fungi or cankers; 2) Stem damage of any kind where wood and so cambium is affected; and 3) Breakage of a stem or even of living root over 20 mm in diameter, which there is a growth loss and it affects the branching type and growth rate. In addition, where soil disturbance is severer, early survival and height and diameter growth are reduced, malformation frequency is increased (Terlesk 1986).

The machine types with the specific modes of operation and the machinery systems to be fitted to harvesting methods have different extent of damages to stands and other vegetation. In two thinning systems mentioned above, the skidder system had much more and severer damage to residual trees than the forwarder system based on different modes of operation, which was assessed by scar size and number of scarred trees per hectare. Operation modes of direct dragging and winching are often more dangerous for the standing trees. Grapple skidding mode will disturb more places, incurring more damage risk to stands. The operating and loading with the crane operation when harvesting and forwarding respectively cause the same problems because visibility is not always free over the zone of action. With no doubt, besides the skills and motivation of operator, amount of injured trees to some extent is caused by uses of unsuitable machinery system and appropriate logging methods as well.

4 Method of integrating assessment of mechanical systems interacting on environmental aspects

In modern mechanised harvesting, influences on the environment aspects are apparent and ineluctable. The assessment of environmental aspects on mechanical systems implicate the integration of processing and analysing multi-parameters of mechanical and biological interaction based definitely on the operability of mechanical systems under the given conditions. The selection of mechanical and environmental parameters and monitoring are of importance to the resonabability of integrating assessment.

4.1 Description of parameters evaluating machines and mechanical systems

From the point of view of optimizing the harvesting system, there might be four groups of parameters to be considered as critical parameters of evaluating the operability and reasonability of harvesting systems. These should include: 1) productivity; 2) cost effective issues; 3) environmental indicators; and 4) ergonomical aspects. In this paper, we concentrate mainly on specifying the influences of harvesting operations on the logging site in the forest. Environmental consequences involve in several aspects of special emphasis on visual forest ground and tree damage assessment in practical way as following descriptions.

Soil compaction

The ground pressure of machine is a key factor in soil compact, which is a function of the weight of a machine on an average area of supporting surface. It can be mainly indicated by the bulk density in relation with ground pressure which is involved in track or tyre types of harvesting machinery. From the environmental requirements point of view, although soil compaction is ineluctable in practice the point is how to minimize the extent of ground pressure impacts on the soil conditions. From the more practical soil inspection point of view after harvesting operation, what kinds of situation that will exist depends strongly on the ground pressure of the machine and mechinery system. It could be categorised as a range of ground pressures, for instance:

- most suitable range
- acceptable completely
- satisfactory
- unacceptable

The ground pressure of a specific machine correspond to the acceptability of harvesting operation in given conditions. It should be noted that there are different range of ground pressures due to machine types with various tires or tracks corresponding to different harvesting methods.

Site disturbances

It can mainly be indicated with the total across-sectional area of disturbances and some extent of the rut formation. The trafficated area of harvesting operation varied as different harvesting systems and logging methods. On the other hand, minimizing the trafficated area is very much dependent on the good operational planning, for instance, reasonable skidding road spacing and operator's skills. In many cases, under the given same conditions there are no big difference of across-sectional area. So, as a critical indicator of soil disturbance, the rut depth could be taken into considerations of site disturbances, which relies mainly on the types, size and inflation pressure of tyres besides the ground pressure of machine. The rut problem on harvesting operation would be categorised as a range of rutted extent as following:

- slight rutted
- accepted rutted
- heavy rutted
- unaccepted rutted

As mentioned, the rut depth results from the impact of various factors. So there are difficulties to some extent to specify reasons for the rut formation. On the basis of specification of each factor, a range of rutted extent could be indicated by an integrated index as a indicator of rut formation.

Damage to stands

This problem is in principle concentrated on the commercial thinning operations. Besides the suitable skidding road spacing needed and operators' skills during operations, types and gauges of harvesting machine are derterminatives in relation with damage to stands. Generally, the more bigger the machines are, the more risk of soil and stands damage they cause. Machines for the cut-to-length system result in less damage to ground floor and stands than machines for tree-length system do (McNeel & Ballard 1992). Machine with a boom-mounted processor is operated at wider spacing; and other type of machine, for instance, feller-buncher and skidder system has to travel to each tree, which could increase the disturbed area and more damage to remaining trees. The assessment of these consequences might emphasise on the structure and dimensions of machinery as following:

- machine size: large, medium and small size
- system type: cut-to-length, tree-length or whole-tree
- operation mode: skidding, winching , processing or loading with crane or boom and forwarding etc.

4.2 Fuzzy method of integrating assessment and analyses

The effect of machines and mechanical system on forest environment is one of aspects that are taken into considerations of evaluating the adaptability and optimisation on the mechanical system in given conditions. As mentioned at previous section, environmental consequences resulting from the machines interacting with forest land are determined through some critical mechanical parameters. It is facts further more that those parameters are also specified with some of more detail factors. Due to the situations existing at timber harvesting systems, fuzzy models could be established as assessing tools.

Model I

Given, a set of factors, U

$$U = \{ u_1 , u_2 , \ldots , u_n \} \qquad (1)$$

and a set of evaluations (fuzzy set), V

$$V = \{ v_1 , v_2 , \ldots , v_m \} \qquad (2)$$

when evaluating a set of factors respectively, significance of each factor affecting the integrating evaluation can be indicated as a weight in a set of factors' range. It is expressed as a fuzzy vector, given A, relating to the U set; that is

$$A = (a_1 , a_2 , \ldots , a_n) \qquad (3)$$

where a_i is a weight of i^{th} factor (i = 1, 2, …, n *)*, and it is satisfied with

$$\sum_{i=1}^{n} a_i = 1 \qquad (4)$$

Evaluating n factors of U set respectively, a fuzzy evaluating matrix can be formed as following, let it be R

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (5)$$

Suppose that the vector A be defined as an input of the evaluating system; and let's say that matrix R is a transformation of fuzzy relationship. Then, as a output, final results could be expressed as, given, B

$$B = A \circ R$$

$$= (a_1 , a_2 , \ldots, a_n) \circ \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} (6)$$

where $\circ$ expresses a multiplication of fuzzy matrix based on the max-min operand rules.

Model II

In the cases of too many parameters and complicated situations, evaluating procedure can be gradually accomplished according to different level of parameters. As Model I, given fuzzy sets of U and V, set U is divided into some subgroups; that is

$$\bigcup_{i=1}^{p} U_i = U,$$

$$U_i \cap U_j = \Phi, \quad i \neq j; \qquad (7)$$

Thus, U has been divided into p subsets; these are

$$U = (U_1, \quad U_2, \quad \ldots, \quad U_p\}; \qquad (8)$$

For each U_i, according to Model I, results of first evaluation could be as follow, B_i

$$B_i = A_i \circ R_i = (b_{i1}, b_{i2}, .., b_{ip}) \qquad (9)$$

where, A_i is a set of weight corresponding to the U_i subset; and the R_i is a matrix of fuzzy transformation

$$\text{Let R} = \begin{bmatrix} B_1 \\ B_2 \\ \dots \\ B_p \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ b_{p1} & b_{p2} & \cdots & b_{pm} \end{bmatrix} \quad (10)$$

As a whole, suppose that fuzzy vector A be a weight range corresponding to the p subsets of U set, i.e.

$$A = (a_1, \ a_2, \ \dots, \ a_p) \qquad (11)$$

then, final results could be expressed as

$$B = A \circ R \qquad (12)$$

In fact, Model II is a second hierarchical evaluation model. Theoretically, there could be more detail model in multi-hierarchy depending on the complexity of system evaluation. For the purpose of solving problem concerned, there are several critical points to be discussed below.

- It is first point to carefully determine the weight range of the evaluating factors. Environmental constraint is one of the aspects affecting on the optimisation of harvesting system. It exists in different significance for the each factor to be taken into considerations. It might be different for the same factor to give rise to system evaluation under different situation, for instance, at different logging methods etc.
- In practice, due to complexity of system evaluation with multi-parameters, the max-min operand rule is not fitted with resolving of system evaluation problems in many cases. For this reason, based on the matrix of fuzzy relation, fuzzy linear weighted transformation is introduced as the treatment of solution as following, given matrix of fuzzy transformation

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (13)$$

and a weight in a set of factors' range

$$A = (a_1, \ a_2, \ \dots, \ a_n), \ \text{here} \ \sum_{i=1}^{n} a_i = 1 \qquad (14)$$

then, results of system evaluation B:

$$\begin{aligned} B &= A \circ R \\ &= (a_1, a_2, .., a_n) \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \qquad (15) \\ &= b_1, b_2, .., b_m) \end{aligned}$$

where

$$b_j = \sum_{k=1}^{n} a_k \cdot r_{kj} \qquad (j = 1, 2, \dots, m)$$

5 Defining Index's method of forest machine performance

5.1 Standpoints of fuzzy assessment in identifying the influences on forest environment

In order to adequately reflect the impact the machines and mechanical system would have on the forest environment, we have to identify indicators that indicate the environmental consequences of harvesting activities and define the measurements of those impact caused by various kinds of parameters. In many cases, those impact would obviously result from the aggregation with respect to the multi-factors. A meaningful indicator reflecting the overall impact on the forest environment should be simple, but in some sense it might be expressed mathematically. The key problem of environment performance measurement is converting large amounts of data into managerially useful information via appropriate matrices (Tyteca, 1996). According to analyses referring to activities of harvesting operations above, many of the quantities to be measured are naturally expressed in physical and biological units. Normalizing those quantities can introduce a uniformity of measurement, which will also result in unitless or dimentionless measures. It is harmonized with the fuzzy method of an integrated assessment to be standardised in order to allow for proper and easy comparisons. Thus, we could define an indicator such that

$$\theta \in (0,\ 1) \quad \text{or} \quad \theta \in [0,\ 1] \tag{16}$$

with 0 and 1 being the worst and best possible values, respectively. First expression means that no absolute the worst and best value can be achieved in the open interval. On the other, the closed interval refers to worst and best observed value at more practical situation, instead. With the range of upper bound and lower bound, it is indicated as the some extent of environmental consequence in a particular parameter. An indicator can be relative or absolute, depending upon what the situation exists in the practice of integrated assessment. For instance, in the pre-operational analysis we frequently define a relative quantity as being the result of the comparison with different machines or mechanical systems. From the technical point of view, defining an absolute quantity can be utilized as an index of improving the technology, functionality, characteristics of the machines or even regulatory standards.

5.2 Index's method – machine performance indicator

Defining forest machine performance indicators as tools to assess environmental consequences on timber harvesting operations, it involves the critical parameters to be specified in relation with the interaction of machine and forest land. The indexes can range from very simple indicators to more aggregated ones. From the point of view on wood procurement, it is dependent on the harvesting operations, for instance, being the differences among the clear-cutting and thinning operations. In many cases, for those parameters which directly indicate the system capacities, functionality and so forth, we can define the machine performance index as follow:

$$\text{machine performance index} = \mathrm{AL} / \mathrm{SL} \qquad (17)$$

in which AL equals to actual machine performance level in a specified parameter for the given harvesting machine, and SL equals to the standard machine performance level corresponding to the types of harvesting operations. The standard level can result from the work study and efficiency research and so on. In the case that an index should be determined by the multi-parameter, for example, indicator soil compaction caused by the several mechanical parameters, travel times in that area and operator skills etc., we can simply define the machine performance index by the weighted average methods,

$$\text{machine performance index} = \frac{1}{n}\sum_{i=1}^{n}\left(\mathrm{AL}_i / \mathrm{SL}_i\right)\bullet \mathrm{weight}_i \qquad (18)$$

in which $\mathrm{AL}_i/\mathrm{SL}_i$ can be calculated according to the equation (17) methods; and weight_i is satisfied with the condition $\sum \mathrm{weight}_i = 1$, which means the extent of the significance in relation with the different parameters respectively.

Let's back to the description of fuzzy model. in fuzzy model I and II, elements of fuzzy relation matrix R involve the fuzzy measure with respect to a fuzzy set of assessment in a set of factors U. Each element, as a characteristic function, letting it be $\mu_A(u)$ indicates the grade of membership of u in A. Here, as the valuation set is allowed to be the real interval [0,1], A is called a fuzzy set (Zadeh, 1956). The more closer the value is to 1, the more u belongs to A. A is a subset of U that has no sharp boundary. So far we are ready to define another method which calculates a value of the machine performance index according to the characteristic function in relation with a fuzzy set. For the purposes of assessment on forest machine pe'rformance, each elements of matrix R in the fuzzy model can be resolved by means of a specified fuzzy characteristic function $\mu_A(u)$ corresponding to the specific parameter in the given situations. Actually, there are different methods to determine the value of $\mu_A(u)$. In some cases, $\mu_A(u)$ might be determined by the fuzzy statistic method. According to the conclusions of He Z.(1984), most common methods to be used in practice are as follow,

Hamming distances or weighted Hamming distances

Let A and B be subsets of the factors set U respectively, i.e.

$$\delta(A,B) = \frac{1}{n} d(A,B)$$

$$= \frac{1}{n}\sum_{i=1}^{n} \mu_A(u_i) - \mu_B(u_i) \qquad \text{or}$$

$$\delta_w(A, B) = \frac{1}{n}\sum_{i=1}^{n}\omega(u_i)|\mu_A(u_i)-\mu_B(u_i)| \quad (19)$$

in which $\omega(u_i)$ is a weight relating to the u_i in U.

Several **fuzzy characteristic functions** can be selected, depending on what kinds of situation exists. As a value of u is smaller, descending half normal distribution or linear function are used as follow,

1) $\mu(u) = e^{-ku^2}$ or

$\mu(u) = {}^{1}\!/_{1+ku^2} \; (k>0)$ or

2) $\mu(u) =$

$$\begin{cases} 1 & (0 \le u \le a_1) \\ (a_2-u)/(a_2-a_1) & (a_1 \le u \le a_2) \\ 0 & (a_2 < u) \end{cases} \quad (20)$$

when a value of u is larger, ascending ones are used as follow,

1) $\mu(u) = \begin{cases} 0 & (0 \le u \le a \\ 1-e^{-k(u-a)^2} & (a < u) \end{cases}$,

$\mu(u) =$

2) $$\begin{cases} 1 & (0 \le u \le a_1) \\ (u-a_1)/(a_2-a_1) & (a_1 < u < a_2). \\ 0 & (a_2 \le u) \end{cases} \quad (21)$$

It is facts that there are also other types of fuzzy distribution to be chosen in real world. Due to relativity of assessment of forest machine performances, linear characteristic function $\mu(u)$ is simply used in many cases. On the other hand, it is fact that a value of $\mu(u)$ in real interval [0, 1] can be defined as an index of forest machine performance relating to a specific parameter in the way of fuzzy sets.

6 Discussion and Conclusion

In this paper three critical factors as the basis of assessing harvesting operations are discussed. In fact any one of environmental consequences should result from the aggregated factors, i.e. some difficulties take naturally place in the recognition of parameters and proper and objective quantification or measurement relating to harvesting machine performance. At this point defining an index method allow us to conduct some kind of comparison in the given standpoint; and go further to identify the various environmental impacts of harvesting operations for the purpose of fuzzy integrated assessment.

1) Fuzzy assessing model and index method

In fuzzy model, there is a crucial stage of processing the input and transformation of information, which account for the matrix of fuzzy relation transformation by means of harvesting machine performance index. In doing so, the measurement and evaluation basis should be harmonized in accordance with the definition of performance indexes. On the other hand, in the case that use fuzzy characteristic function $\mu(u)$ 1) to form fuzzy matrix, it must be very careful to identify the distribution of fuzzy characteristic function, provided that it plays a determinative role in the integrated assessment of harvesting operations.

2) Interpretation of fuzzy integrated assessment

An effective result of fuzzy assessment is situated in the interval [0, 1] in which the closer the value of result is to 1, the more relative the interaction between machine or mechanical system and forest environment is under the given conditions. Assessing environmental consequences of harvesting operations could focus influences of environmental parameters on individual forest machine. In the case of involving comparison with different machines or mechanical systems, result of assessment is a relative in the same conditions.

3) Pre-operational and post-operational assessment

Generally, for the purpose of optimising harvesting system, assessing the interaction of machine and forest ground should be done during harvesting planning in order to identify the extent of influences of harvesting operation on forest environment. But in practice specifying environmental consequences of machine behaviour are based on the monitoring, observation, analysis and evaluation during harvesting operations. There in fact exists affirmation of some parameters in fuzzy assessing model that involve the interrelation between machine parameters and environmental parameters. It is of great significance that the interrelation of machine acting on forest environment could be determined so as to facilitating the pre-operational assessment relating to harvesting operations.

References

Abeels, P.F.J. 1994. Mechanisation of the forest operations and impacts on the environment. FAO/ECE/ILO: " Soil, Tree, Machine Interactions", July 4–8, 1994. Feldafing-Muenchen, Germany. No. 5.

Abeels, P.F.J. 1994. Environmental consequences of operations in forest. Scandinavian Forest Research in Europe: Operational Research. NSR Research Conference 1994. p. 32–40.

Dubois, D. & Prade, H. 1980. Fuzzy sets and Systems: Theory and Applications. Volume 144 in Mathematics in Science and engineering. Academic Press, Inc.

Wästerlund, I. 1994. Ground pressure, Slippage and soil damage. Scandinavian Forest Research in Europe: Operational Research. NSR Research Conference 1994. p. 156–167.

Hakkila, P. 1995. Harvesting timbercrops in Finland. Profitable harvesting, The Finnish Foreign Trade Association. p. 2–4.

He, Z. 1984. Fuzzy mathematics and applications. Tianjing Science and Technology Press, Tianjing, P.R. China (in Chinese). p. 374–377.

Koger, J.L. et al. 1984. Skidder tire size vs. soil compaction in soil bins. Transactions of the American Society of Agricultural Engineers. 27(3): 665–669.

McNeel, J.F. & Ballard, T.M. 1992. Analysis of site impacts from with a harvester and forwarder system. Journal of Forest Engineering 4(1): 23–29.

Sherar, J.R. 1986. Environmental influences affecting machine performance and Selection in the Southeastern United States. In: Staurt, W.B. (ed.). Proceedings of Harvesting Machines and System Evaluation Workshop. Charleton, South Carolinna, USA. p. 197–201.

Strokes, B.J. et al. 1994. Biological and Mechanical System Interactions – What do we know?. FAO/ECE/ILO: “ Soil, Tree, Machine Interactions”, July 4–8, 1994. Feldafing - Muenchen, Germany. No. 27.

Tyteca, D. 1996. On the Measurement of the Environmental Performance of Firm – A Literature Review and a Productive Efficiency Perspective. Journal of Environmental Management, 46. p. 281–308.

Terlesk, C.J. 1986. Harvesting machines and systems evaluation: Environmental Considerations. Proceeding Harvesting Machines and System Evaluation Workshop. South Carolina, USA November 18–19. p. 177–186.