1 The importance of the topic and the background of the research

The multipurpose use of the forest is important for the whole fauna, pre-eminently for existence and perpetuation of the human society. The multipurpose use is realizable if – completing the rules of the nature – humanity society influences the functionality of the forest.

The wood produced in the forest is the environment-friendly and is a natural primary product for the economy- representing at the same time income for forestry.

The circumstances of wood exploitation are rooted in ecology, economy, social welfare, and community needs. The dissertation is preoccupied with the executive part of the increment and selection thinning, taking serious consideration of the above mentioned circumstances. The execution is realized using social mechanical, so-called wood harvesting systems.

Movements, defined in major part by machineries, characterize the wood harvesting systems. The structure of a system is recognized by the order of the actions, defined in the wood harvesting as changeable on characteristic of premises. The need for structuring is clear when one wants to collect the wood harvesting methods.

1.1 Chronological review

The inventor of this particular research discipline could be *Taylor,* applying the sophisticated time-study to improve work capacity. He defined the capacity of the workforce atomizing the tasks and measuring its parts as what extent they are time-consuming. This procedure is applied even today.

In Hungary for the First time Béla *Török* wrote a report in this topic: "The rationalization of the forest utilization work". This article might have been considered to be the beginning of this particular discipline.

The first publication of the Hungarian results of a forest utilization time-study was made in 1932 by *Török* and *Plauder*. They select the work-force, made device improvement, paying attention to precise organization and equitable payment.

In 1950 the research on wood utilization was eminently preoccupied with the development of the hand devices and examining the work actions. The most important essay from this time was about the clear cutting made in flat oak high forests.

In the beginning of the '70s a government decision effective in Hungary to promote company organization, followed by the directives of implementations, too.

In the years '70 and '80s research on work-system of the wood utilization was on top in Hungary, due to the Department of Forestry of the University of Forestry and Wood Science. In those days was developed the "Sopron Sequential Analysis Method" (SSM) was developed so as to support economic decisions with applied mathematics.

In 1985 the Forest Research Institute (ERTI) funded the Technological Developer Group, with the task to develop work-techniques, operation technologies and work-systems.

In the last 15 years the Hungarian foresters' society showed less interest on this research.

However, in West-Europe development of work-systems, technologies and executions in wood utilization are still on top. The principles have changed abroad characterized in one hand by the harvester-forwarder work-systems, work-execution, in other hand by the expansion of the independent work-organization.

2 Research aim and Methodology

2.1 The aim of the research

The aim of the research on wood harvesting systems is: Task-oriented optimal harmonization of the person, the tool, the work-task and the technology. The aims of the present research are to be identified as follows:

- Give an overview of the research done in work-systems.
- Present the results on operation analysis.
- Point out the importance of the human part; analyze the potential danger caused to a worker.
- Analyze problems solved with algorithms connected to the tasks of the work.
- Give a method for counting the operation hour costs.
- Present - through examples - the opportunities for operation-analysis and planning.
- Classify the harvesting methods used in thinning.
- Give a method for catalogue the harvesting systems.
- Summarize the Hungarian harvesting procedures illustrated with cost-analysis specific for adaptation.
- Present a cost-calculation method usable in work-system analysis.
- Illustrate the use of work-system analysis in substantiating economic decisions.
- Give a method for examination of harvesting systems' environmental response.

2.2 The methods of the research

Data acquisition methods: Analysis of labour statistics, interviews, questionnaires, processing working day registration and account.

Work-study methods: Defining tasks, division of act-periods, fixing measurement places, defining work-cycles, time-accounting, register bearing bases and influencing factors, count of the time-algorithm, producing of norm-tables, count of the operation hour costs and define the process costs.

The methods for developing technologies: Anticipatory technology-analysis and development, preparation of the experience, data-registration and execution of the experiment, data processing, evaluation and analysis.

Sopron Sequential Analysis Method (*Herpay – Rumpf* and others)
- Building of work-systems and alternatives for work-systems from operations.
- Definition of time- and cost-algorithms for operations.
- Analysis of work-systems' operations (productivity, cost, use of energy).
- Harmonization of the parts of a work-system.
- Appreciation and comparison of the work-systems.

The cost-analysis applied in the process of the work-systems is the so-called normative cost-calculation. This is based on the norm-times and time-algorithm and the operating hours' costs – based on normal purchase price, normal time of use, normative repair share, etc. – are calculated using algorithms.

3   Presentation of the results of the research

3.1   The examination of the wood-harvesting work-systems' operation

<u>Marking the trees with marking tape</u>
In Hungary trees denoted for exploitation in thinning are marked with timber scribe. Its disadvantages: other denotation means other wound for the trees, in denotation is hard to "overview" the stand and the marks are hard to be seen. Colour marking tapes are adaptable to denote the exploitable trees. These could be seen from all sides and distance giving a better overview of the stand and better planning of the trees denoted for exploitation and the denotation is changeable. After a tape-denotation the productivity of the felling is higher with 30 % than in denotation with timber scribes.

<u>The cutting-capacity of the chain saws</u>
The determination of the cutting capacity of the chain saws was done on Scotch pine and oak. From analyzing the cutting of 2 800 wood-circlets are ascertainable:
- It is possible to define the optimal adaptability of a type of chain saw.
- The optimum for a powerful chain saw is on a bigger diameter than a powerless one.
- The same saw has a higher cutting efficiency in pine than in hard-wood tree.
- Using chain shaped correctly – in the same conditions – shows double efficiency than with used one.

The chain saw extension scale and the chain saw side-stick shows to be a beneficial accessory tool for chain saws. Using them one can admeasure lengths of 1 m, eliminating separate gauge in bucking of the standing trees and group bucking.

<u>Felling methods</u>
Expert work-technique used in thin tree felling: Felling with chamfer cut, felling with strapping, felling with undercut cutting. The felling with chamfer cut and with strapping is useable at a diameter up to 15 cm, the felling with undercut cutting up to 20 cm. At a diameter above 20 cm the only one acceptable felling technique is the one with undercut. Negative threshold high is admissible only on felling with winch.

<u>Limbing techniques</u>
Adapted work-techniques for limbing with chain saw – due to the regular whorls – are used primarily in coniferous trees. The most common technique is the six-point method. With one cut several whorls' bushy, thin twigs can be removed. Limbing such a tree is realizable using the balance-method. Cutting down long, thick branch is realizable using the roof-method, named as crested method too. In general limbing broadleaved means combining elements of limbing techniques of coniferous trees, in accordance with the situation given.

<u>The BEYA method</u>
Limbing felled trees is labour-intensive, needs leaned work-position with the danger of cutting in the topsoil. For these reasons several wood-conspicuous or difficult methods were invented for lifting – during the limbing – the tree: Swedish buck method, rolling buck method, etc.
I worked out and improved with Austrian colleague Alfred *Bernhard* the BEYA method. The felled tree, with a diameter at breast high between 8-15 cm must to be hung at ancon high to a stand tree using a log tong and a strap. This way during the limbing the tree is in a "comfortable" high (between knee and hip high) so the worker is not forced for leaned work-position and the lower side of the tree is accessible for the chain saw. The method described was for the first time applied in Austria. This experiment resulted a work-time-study and several ergonomic (heart-rhythm count) measurements. The capacity showed of the 0,64

m^3/whr at trees with a diameter of 12 cm is higher in intermediate skidded material than the EST (German) standard and better than the productivity of the Swedish buck method.

The ascension of the average pulse-number during the whole working time is 31, less lowly than the admissible 35. The role of the chain saw is just the 42 % of the total working time. The chain saw work-periods alternate with the vibration-free periods, leaving time for regeneration.

Bucking of the standing trees
In thinning trees got stuck during felling causes big problems. Mostly these trees are bucked without the necessary work-security precautions and the parts left are not the accordant size. In the developed method the chain saw extension scale gives opportunity for dimension exactness, the work did as it was planed is safety on trees at a diameter lower than 15 cm and is ergonomically favourable. Due to a proper work the wood material will accumulate.

Group bucking
This action is needed when the long log skidded cannot be transported in this form. The ballast tracked on a simple workbench can be bucked in group using a chain saw with chain saw side-stick.

Hand skidding devices
The log tong is useful in the thin, long (3-5 m) assortments as well as long trees manual skidding. It is no need for deep flexion catching a tree; the wood material can be traced and left easier.
The lifting hook in long-log skidding is used in pair, in bunching and stacking in pair or single. In the last mentioned operations is advantageous the use of extended handled hook. The bit on the handle as well as the machete-like design made possible the excising knot too.
The "sappie" (hokaroon) is utilizable in intermediate skidding of long wood-material hard executable with a log tong, but is useful in arranging stacks.

Horse skidding
Skidding using animal forces is far more the oldest method practiced.
For skidding are practicable to use horses between 600-800 kg weight and 1,60 m high. Horses are applied in thinning and intermediate skidding, on plane or maximum 30 % declination surface. After a 1-12 month instruction period a horse can be used for forest utilization 5-8 years from age of 3-4 years. The decline of the horse skidding method is due to the need for everyday care of a horse.
Long log horse skidding is practicable using hauling chain, chain ball, bogie cart, skidding pan, rubber panel harness and the overflow-framed sledge. Skidding short wood material can be done using sledge, wheel-pair and horse-pulled cart.

Analysis of pulling force of the horse skidding devices:
From the point of view of the horse loading the sledge skidding – as its name shows – is practicable during the winter, otherwise the wheeled skidding is favourable. Using overflow-framed sledge the horse is not extremely overload, however the specific pulling force need is relative higher. Sledging and skidding on forest soils are not the best practices for horses as well as for the specific pulling force need. The maximal pulling force need is in average 2,9 higher than the specific pulling force need. During skidding this could be even 4,9 higher.

Skidding using small machines
The horse skidding is a traditional, environmental friendly, tolerant way of tree utilization. The disadvantage of this technique is the horse itself: it cannot be turned off; it needs care during the relaxation period. To subsidy horses in the forest one can use machines with small dimensions and weight.

Grapple small tractor. Using my plan was manufactured a hydraulic grapple mountable on small tractors (TZ-4 K-14B and Rába 15), practicable for skidding thin wood material loads as well as thinner trees.

Skidding using chute is known in forestry since ages. Its oldest versions are the different forms of wooden chute, then the different forms of plate and – recently – plastic chutes are in use. Its advantage is the low cost considering specific wood material concentration; its disadvantage – considering a modern plastic chute – is its price.

The small winch skidders first of all are special forest machines usable for skidding. Such are the DFU-451 and the Iwafuji T15 or T30.

Earth-commanded tractors. These small machines cannot be got on; its conduction is done from near by. Such is the iron horse, whose rubber foot is very tolerant with the forest soil.

Winch works with chain saw power. Most types, anchored to a tree, are used for skidding. Its big advantage is its easy transportation.

Small cable-crane. The carriage with a pulley works with chain saw power, running on a skyline mounted on standing trees. Its is very similar to its biggest brother, but its very simple, its easy to move and used in thinning in a tolerant way.

Origin-identification, quality-insurance
Today the crayoned, the numbering hammered and the marking painted wood material labelling are in practice. These are or hard distinguishable, or less informational, or not enough all-weathered. The use of visible, informational all weather plastic disk counter-systems can eliminate all these defects. The colour plastic disks fitted in the butt-edge identify the assortment individually, follows it until the processor unit and using distinct marks it can be used for origin-identification.

3.2 Human factor

Due to the heaviness of the tasks, the work-environment, the responsibility of a worker and the statistics of the accidents the wood exploitation is considered one of the hardest craft.

Hungarian and Finnish research institutes in association followed the accident issued felling situations. Based on a video-technique examination method finalized with my collaboration showed the "near accident" actions, what are its reasons and how can be avoided.

The Finnish-Hungarian experiment demonstrates the importance of the safety provision tools for workers. In wood exploitation these are: Hardhat with eye protection and ear protection, jacket with colour line, safety gloves and protective trousers with cutting-inset and safety boots with steel- and cutting-inset. The full price of a set of protective equipment is half of an 80 cm^3 chain saws.

The optimum for human performance
I did research on intermediate skidding with manual skidding scissor. Using the resulted data I calculated the time for in function of the volume of the skidded tree. This helped me to calculate the performance for specific time-consume of 1 m load-run. Based on the resulted graphic it can be stated that worker doing intermediate skidding with manual skidding scissor has an optimum for its productivity.

3.3 Time utilization in tree harvesting and skidding

For certain reason the available labour-time (labour-time fund, number of yearly operation hour) is not totally used by the workers (live work) nor the exploiter machines (dead-work) The percentage of the effective work (utile work) and the disposable time is defined as working time-utilization index (P) in our country. I made national surveys to define the lost time and the working-time composition in wood exploitation and tree skidding. In wood exploitation the lost time caused by the weather is the biggest, followed by the machine-damages, than the in -organization As a result of the survey can be shown that in Hungary

the time-utilization is 56,85 % in wood exploitation, and 60,97 % in skidding. Based on this data the average time-utilization index (P) on 60 % used in common calculations is acceptable.

3.4   The analysis of the subject of the work

I developed a method for calculating from the diameter at breast and the height of the tree the dimensions of the assortments left after bucking. Using the form-lines by species given by *Sopp*, I modelled the trees, using line-calculation. I determine the following assortments' middle diameter, size than the average size of the assortments. The developed calculation method made possible (knowing the guidelines for conversion into assortments) the eligibility of the right forwarding utility (forwarder, skidder) and its work's planning before the beginning of the wood exploitation.

If the distribution of the diameter at breast by girth class of the exploitable stand the calculations can be done for each girth class resulting – weighted with its distribution – the average size of the assortments logged from a stand. Naturally the average size of one assortment can be calculated presuming that in a turn the forwarder takes assortments with the same (or similar) size.

3.5   Calculation of the machine cost

The operating hour costs of the exploitation machines and devices are important in calculating the total costs by operations and by exploitation. For this reason comparing the literature in this field I determined the basic and calculated data for machine cost, this way the yearly operating time, the amortization period, the repair percentage, the fuel-consumption and other components of the operating hour cost. Using different basic data I determined the fuel-consumption's normative equations for chain saws, tractors and trucks. To calculate the machine cost I used an equation resulting from the Hungarian calculation schema and the FAO-ECE schema. This way I determined the operating hour cost for 76 different machine and device and I detected the structure of the different machine-groups' operating hour cost. Basing on the literature found I configured a reduced calculation formula to estimate the operating hour cost for non-motorized forest devices and motorized machines.

3.6 Analysis and planning of the operations

On the felling-buncher machines, the forwarders and the winch skidders as examples, I present through calculations the opportunities of planning the wood exploitation. In the winch skidder's example I present the method developed for the impact study of the factors influencing the cost-equation. Its principle is a calculation process displaying the influence of the individual factors on the specific cost. Presenting the results in a graphic followed a, so-called mirroring process; the influencing factors' influence-order can be seen visually.

3.7 The description of the wood exploitation work systems

Work-system classifications
Many alternative solutions are used to classify tree harvesting work-systems. Classifications are by the specific machine, the degree of the mechanization, the length of the tree during the skidding or transportation and its level of processing, the concentration in space of the works and the place of processing the tree.
Basic tree harvesting work systems:
- Whole-tree system
- Long-tree system
- Short-wood system
- Chipping system
- Combined system

Several specific representation for work systems: table description, description schema with formula, process charts, characteristic chart with band diagrams, top-view schemas, far-seeing illustrated representations and insight illustrated representations.

I developed a description based on the table schema. In the first field of the table the description of the work system is given, informing about the operations, machines/devices, place of execution and number of participants. In the second field the cost calculation of the work system given can be made for a specific forest stand or specific implication. The following fields are to present the application limits (stand type, diameter-limit, declination-categories, implications' shares), tolerance - ability and spatial order of the work system. The table can be complemented with a detailed description of the work system. The schema gives the opportunity to all reproduce the whole catalogue of the work systems, which is permanently revised.

The work systems practicable in Hungary today – and which are illustrated with specific schemas with calculation examples – are:

- Short-wood system with horse (horse with wheel-pair, horse sledge)
- Long-tree system with horse (horse with chain)
- Short-wood system trailer tractor
- Short-wood system with grappled tractor
- Long-tree system with winched tractor
- Short-wood system with winch-skidders (unit package)
- Long-tree system with winch-skidders (LKT)
- Short-wood system with farm tractor and forwarding device
- Short-wood system with forwarder
- Short-wood system with cable crane

3.8 The uses of the analysis of the work-systems

Analysis of methods to sustain economic decisions
Calculating normative direct cost by species for the third grade and by diameter at breast classes. The normative times were used from simplified tables by species. The costs calculated by operations gives the specific cost of the work system. The cost calculated this way are direct wood exploitation and tree utilization costs, which are increased with the branch, factory and company costs as well as the normal profit. The results of the calculations can be used for yearly cost planning, economical profitability calculation of the species, forest assets calculation and in defining the income-productivity of a forest.

Environmental tolerance of the work systems
The method developed by me took in account the impact of the forest exploitation on the other elements of the environment as well. The principle is: Enumerate the damages caused by tree harvesting giving them a certain weight. The result is two scales. The one is the "Intolerance index" containing all the damages. The other is used in calculation of the "Environmental intolerance index" containing the environmental damages. In the "Tree harvesting intolerance matrix" table is enumerate the whole possible work-operation in a wood exploitation and its executive tools. The matrix gives the operations and executive methods causing certain damage and contains the calculated tolerance indexes, too. Analyzing certain work systems from the matrix an extract – containing the operations of the work system given – has to be made. This contains the tolerance indexes of the work system given. Many such an extracts – on work systems or versions of work system – can be made from the basic matrix. The evaluative method can be flexible applied to estimate work systems in accordance with its tolerance.

Calculation of the cost by assortments
Using the "Sopron Sequential Analysis Method", the cost-analysis by operations can be used to define the production costs by assortments also. Just the occurred operational costs are counted in an individual assortment's cost, as well as in the proportion occurred at that assortment. Confronting the costs and prices by assortments can be shown, which are economically produced and which aren't.

4 Theses

- Analyzing the cutting-performance of the chain saw the optimal adaptability parameters of a machine-type can be located.

- The BEYA method is a new procedure, offering ergonomically favourable work conditions in coniferous thinning.

- Research on bucking of standing trees generated new dimensions in the field of work; the safety-technically prohibited method was authorized.

- The application of the horse skidding is decreasing, but the analysis of pulling force need and especially the development of skidding devices generated changes.

- The analysis of small machines substituting horses, especially the development of the grappled small tractor helps to the development of the "small scale forestry's" tree harvesting.

- The developed accidental argument-research method gives an opportunity to reveal the dangers and its roots and gives guidelines to avoid them.

- Optimizing the manual skidding is a new result fostering the humanization of the logging.

- The calculative method to determine the assortments' volume is a new result, giving the chance to predetermine the size of the piece from the diameter at breast and the height of a tree.

- The reflective method developed for estimating the anticipated effects made possible a right estimation of the estimation of the factors influencing productivity costs.

- Distinct result is the own developed work-system as well as its alternatives.

- New result is the schema developed for describing work-systems, giving the opportunity for a flexible registering and classification of the work-systems, using the chance to overtake specific calculations as well.

- The new method developed to analyze the environmental tolerance of the work systems can be used with great success in deciding the general tolerance.

- The method to estimate the costs by assortments and the calculative method for estimate the profitability deduced gives the opportunity for a real estimation of the individual assortments promoting sustainable economic decisions.

5 The possibilities for the practical application of the findings

- The method of time- and cost-analysis publicized – in a common work with János *Rumpf* – as lecture notes in a DAAD-FORNET publication in Freiburg has been used.

- Several results from above mentioned – primarily operation-developments and device-developments – were introduced in practice. This way were manufactured hand tools, horse skidding devices and small tractors' grapple. The BEYA method was introduced; the bucking of standing trees methods and the operation techniques are being used.

- The accidental argument-research method was developed.

- To choose the right chain saw the described results of the cutting-capacity analysis is practicable.

- The calculative method to determine the measure of the piece is practicable, the fuel-consumption calculative method and the simplified machine cost estimation formulas are useable.

- The major part of the described work-techniques were introduced in the education system, the hand tools and the mini cable-crane are used in practice by the forest-engineering colleges.

- In forest-engineer education we use the methods to estimate the environmental acceptability of a work-system.

- The work-system description schema and the cost and profit calculative method by assortment are ready to be introduced.

- There is a 45 piece of 180 minute video-documentary archive about the work-systems described and developed.

- The developed techniques have been presented within the country - 396 lectures and 45 practice presentations.

- Five forest holding company-workers, experienced in wood exploitations, learned the developed techniques and work-systems.

- I wrote an expert-engineer lecture note about the methods of technology-analysis and technology-development.

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