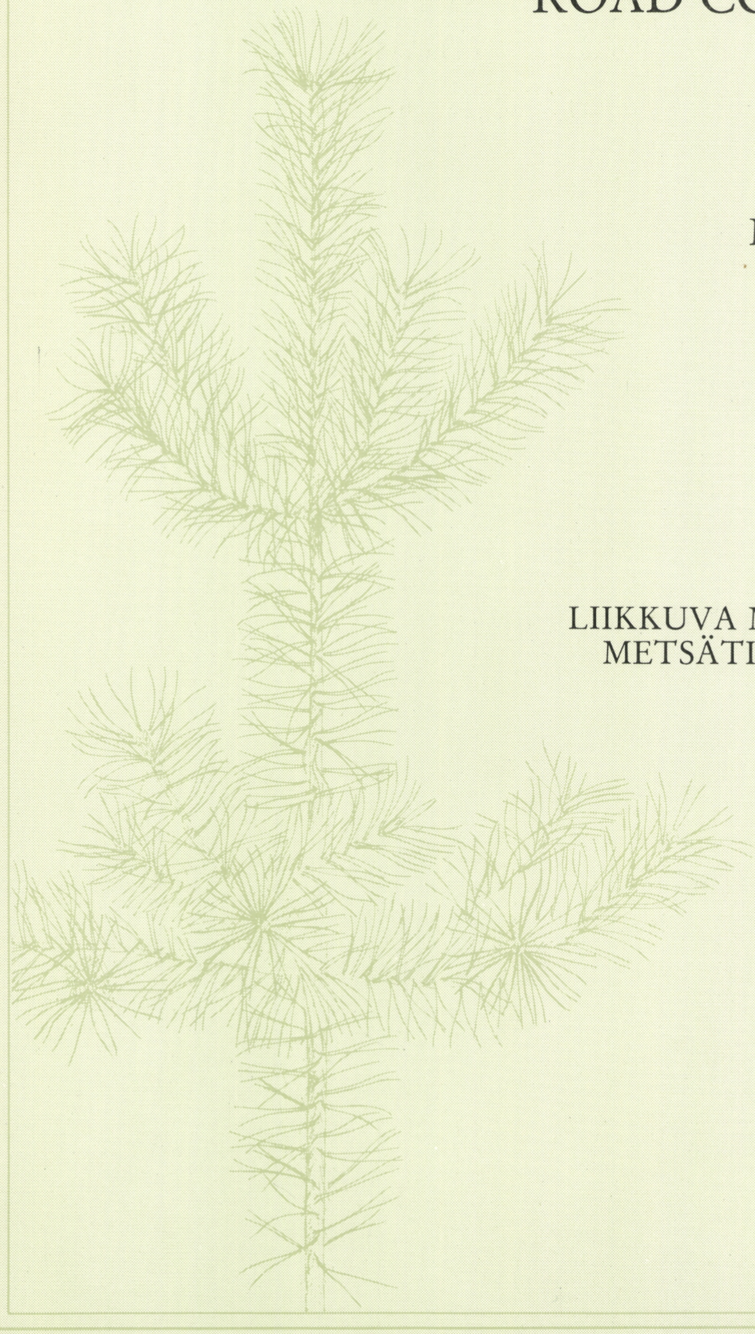
COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 107

A MOBILE CRUSHER FOR FOREST ROAD CONSTRUCTION

REINO PULKKI &
MATTI AITOLAHTI



SELOSTE

LIIKKUVA MOREENINMURSKAIN METSÄTIEN RAKENTAMISESSA

HELSINKI 1982

COMMUNICATIONES INSTITUTI
FORESTALIS FENNIAE

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Publications of the Finnish Forest Research Institute:

- Communicationes Instituti Forestalis Fenniae (Commun. Inst. For. Fenn.)
- Folia Forestalia (Folia For.)
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Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

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PULKKI, R. & AITOLAHTI, M.. A mobile crusher for forest road construction. Seloste: Liikkuva moreeninmurskain metsätien rakentamisessa. Commun. Inst. For. Fenn. 107:1—30.

The report outlines a study analysing the various work methods and feasibility of the Mertsa mobile moraine crusher in forest road pavement contstruction. Recommendations are made for work method and crusher improvements, as well as for new work techniques.

The crushing method resulted on lower road construction costs, compared to conventional gravel hauling, when the hauling distance was over 7 km. By employing improved work techniques the cost of feeder road construction would be lower than conventional gravel hauling, when the hauling distance is over 1 km.

Tutkimuksessa analysoidaan liikkuvan Mertsa-moreeninmurskainjärjestelmän eri työmenetelmiä ja käyttökelpoisuutta metsätien pintakerroksen rakentamisessa. Edelleen annetaan työmenetelmiä koskevia suosituksia sekä murskainta ja työtekniikkaa koskevia parannusehdotuksia.

Murskausmenetelmällä todettiin saatavan tienrakennuskustannukset alenemaan verrattuna tavanomaiseen soran ajoon, kun ajomatka oli yli 7 km. Käyttämällä parannettua työtekniikkaa metsätien rakennuskustannukset alenisivat verrattuna tavanomaiseen soranajomenetelmään, kun ajomatka on yli 1 km.

ODC 383.7
ISBN 951-40-0590-2
ISSN 0358-9609

Helsinki 1982. Valtion painatuskeskus

CONTENTS

PREFACE

This report is the second report of the study carried out on the use of crushed glacial moraines in forest road construction and the crushing systems and methods most applicable to the forest road construction situation. An initial report has been written dealing with the factors affecting the use of crushed glacial moraines in forest road construction. This report deals with the application of a mobile crusher system: how to optimize and improve the system so that minimum road construction costs are achieved.

This report was originally written by R.E. Pulkki. M.H. Aitolahti added the Finnish text and prepared the manuscript for publishing. The manuscript was examined by Prof. Dr. Eero Paavilainen, Prof. Dr. Pentti Hakkila and Dr. Juhani Päivänen.

The authors would like to sincerely thank the Department of Peatland Forestry of the Finnish Forest Research Institute and the Department of Logging and Utilization of Forest Products of the University of Helsinki, who financed this research report. The authors would also like to express their sincere thanks to Mertsalmi Oy for the fine co-operation received from them. Finally, the authors would sincerely like to thank all the people who have given their guidance, comments and support.

Helsinki, April 1982

R.E. Pulkki *M.H. Aitolahti*

1. INTRODUCTION

11. Research subject

Since the 1930's considerable attention has been focused upon how to obtain the most economical forest road network possible. This was largely due to the rapid increase in the transport of wood by truck. Building a forest road network, for example, to a density of 2.5 km/km^2 at roughly 25 000 FIM/km is a considerable investment: approximately 62 500 FIM/km^2. Another factor influencing investments in forest roads in an intensively managed forest is that they are used sporadically and for short durations by heavy haul vehicles. However, no matter how low the traffic density, a forest road must have sufficient supportive strength to bear the maximum loads expected without structural damage occurring.

Many previous studies have dealt with various techniques to minimize the construction and maintenance costs of all-weather and year-round forest roads. For example, Matthews (1942), Putkisto (1956), Larsson (1959) and McNally (1977) have discussed optimal road spacing. Saarilahti (1977) has studied the use of fabrics in the construction of roads on peatlands. McFarlane et al. (1968) outline the use of chemical additives for increasing the bearing capacity of the subgrade and pavement materials. Proper drainage, compaction and location of the road are also important. Savings can also be made by utilizing as much material found directly at or within the immediate vicinity of the work site and by using the most effective work methods, efficiently.

The basic objective of all the above methods is to reduce the quantity of material which has to be hauled to the work site. In the future this will be of increasing importance. Pulkki (1980) has shown that gravel hauling rates have risen considerably since 1973 and that the rate was expected to increase by 48 per cent from 1980 to 1985.

With the development of the Mertsa mobile moraine crusher (Fig. 1, p. 6) the possibility of using poor quality morainic deposits directly at or within the immediate vicinity of the road construction work site has become feasible. Two previous studies have dealt with the use of the Mertsa mobile moraine crusher in forest road construction (Ylä-Hemmilä 1978, 1979). With the use of the mobile crusher technique it appears that forest roads can be built cheaper than with conventional forest road construction techniques. It has also been found that the bearing strength of crushed moraine, on the average, is 45 per cent higher than that of conventional road construction materials and that the increase in the bearing strength is at least 25 per cent, 95 per cent of the time (Pulkki 1980).

The major objectives of this part of the research project were:

1. to analyse the various work methods and the feasibility of the Mertsa mobile moraine crusher system,
2. to search for work method and crusher improvements,
3. to recommend new work techniques and methods if possible and
4. to compare the cost of crushed morainic material produced by the various crushing methods with conventional gravel hauling.

12. Theoretical frame of reference

The field studies were mainly carried out at the research forest of the Finnish Forest Research Institute at Vesijako. One phase of the field work was carried out at a National Board of Roads and Waterways (TVL) work site near Mäntsälä. Methods 1-A and 4 were studied during 5...6.1979, while methods 1-C, 2-A, 2-B and 2-C were studied during 29.10...8.11.1979. These methods were studied at Vesijako. Methods 1-B and 3 were studied near Mäntsälä during 21...23.8. 1979. For the technical data of the Mertsa crusher see Appendix A (p. 30). There was no long-term monitoring of the crusher since the study was concerned with the use of mobile crushers and the work methods involved and was not a machine evaluation report.

The study was limited to studying one mobile crusher, although there may be other possible designs which could be employed. The Mertsa crusher worked single shifts and was operated by the same operator throughout the study. Along with the Mertsa crusher, various excavator models were used and are as follows:

1. Brøyt X-20 (bucket capacity 450 l),
2. RH-6 (bucket capacity 750 l) and
3. Valtra UM-353-CM (bucket capacity 267 l).

Each excavator had a different operator. During the study various combinations of hauling equipment were also employed. Although some general observations were made, the effect of operator performance on the productivity of the system was not studied.

Fig. 1. The Mertsa mobile moraine crusher working at an old gravel pit. A Lännen 1680 M excavator is feeding the crusher.

Kuva. 1. Liikkuva Mertsa moreenimurskain työssä vanhalla sorakuopalla. Syöttökoneena on Lännen 1680 M hydraulinen kaivukone.

2. METHODS AND DATA

21. Data procurement

During the time studies two observation sheets were simultaneously employed when applicable: one for the crusher and excavator and one for the hauling equipment. A continuous survey of the work processes was performed by recording the function each piece of machinery was performing at 30 s intervals. A dot tally of the number of excavator bucket-fulls of material fed to the crusher or the number of dump-box loads, was made on each observation sheet. The observations were tallied according to the time interval in which they occurred. If a move was made (i.e. from a finished borrow pit to a new one) the distance of the move was also recorded. By employing this method an accurate account of each work method was obtained, the interrelations between the various machines determined and the per cent of the working time performing the various processes estimated. The average production of each system could also be determined, during both productive crushing time and total working time.

To obtain the spreading work cycle time for the Fiat tractor, when employing the front bucket for spreading, the total time to complete each work cycle was measured and the location of the spread material marked for subsequent measurement during the construction of a 100 m section of road.

During the time studies the researchers made no attempt to lead the operation; they only recorded what happened as the work progressed. The work sites and the possible roadside locations for crusher feed material were defined by the supervisor and the forest technician for the area. The exact locations for the roadside borrow pits were chosen by the excavator operator, who was an experienced operator in all cases. The old gravel pits in which crushing occurred were chosen by the forest technician.

22. Work methods employed

In past studies carried out by Ylä-Hemmilä (1978, 1979) four work methods were introduced and are as follows:

1. the crusher and the excavator are stationary — the excavator feeds the crusher and the material is crushed and dropped directly onto the hauling vehicle,
2. stockpiling — the material is dropped directly onto the ground and hauled to the road when convenient,
3. the crusher and the excavator move along the roadbed — the material is dropped directly onto the subgrade and as soon as a sufficiently thick layer is obtained they move on (as the excavator feeds the crusher it can also dig the roadside ditches) and
4. the excavator is stationary and the crusher moves back and forth along the roadbed.

Method 3 is impractical since crushed material should only be used on compacted subgrades, otherwise the benefit derived from the crushed material (i.e. increased bearing strength) would be lost. Also when constructing feeder roads, the amount of material from the ditches would be considerably more than would be required for the road pavement. The material from the ditches may be unsuitable for crushing (i.e. excessively wet) and cause choking of the crusher head and sloppy work results.

Method 4 is also impractical since the charge-out rate for the crusher during 1979 was 250 FIM/h. Three gravel trucks could have been hired for the same rate. Therefore, it is felt that the crusher is too expensive and too important to be used as a hauling vehicle.

As a result, various work method combinations of the first two methods specified by Ylä-Hemmilä (1978) and the various equipment employed, were used and are as follows:

1-A. the moraine was crushed directly onto the hauling vehicles at small roadside borrow pits. A Brøyt X-20 excavator was used to feed the crusher and the hauling vehicles were a Volvo N-86 truck and a Fiat 1000 DT Super tractor. A McCormick International 34 tractor with dump box was occasionally used to replace the Volvo truck.

1-B. the moraine was crushed directly onto the hauling vehicles at small roadside borrow pits. A RH-6 excavator was used to feed the crusher and the hauling vehicles were a Sisu Jyry truck and a regular Sisu truck. A medium weight grader (approximately 12 t) was used to spread the crushed material on the road.

1-C. the moraine was crushed directly onto the hauling vehicles at small roadside borrow pits. A Valtra UM-353-CM tractor-digger was used to feed the crusher and a Fiat 1000 DT Super tractor used to haul and spread the crushed material.

2-A. the crushed material was dropped directly into a stockpile on the road subgrade and the borrow pits were from 150 to 500 m apart. A Valtra UM-353-CM tractor-digger was used to feed the crusher and a Fiat 1000 DT Super tractor used to spread the material with the front bucket of the tractor and the grading blade attached under the tractor. Spreading occurred simultaneously with the crushing operation.

2-B. the same as 2-A except that the borrow pit spacing was from 50 to 100 m.

2-C. the same as 2-A except that the borrow pit spacing was 10 m and the spreading operation occurred one day after the crushing operation.

3. the crushed material was dropped directly onto the hauling vehicles and the crushing occurred in a large gravel pit. Otherwise similar to method 1-B.

4. the crushed material was dropped directly into a stockpile and the crushing occurred in a large gravel pit. A Brøyt X-20 excavator was used to feed the crusher and a Fiat 1000 DT Super tractor equipped with dump box used to load, haul and spread the crushed material.

The operating methods were recommended by the researchers. The actual feeding machines and hauling vehicles employed depended upon their availability however.

The top size of the crushed material for all the methods, except for method 4, was from 55 to 66 mm. The top size of the material produced during method 4 was from 28 to 33 mm.

23. Data analysis

Time study: For each method the total number of observations for each process were summed and the per cent of the total time performing the various processes calculated. The sampling method can be classed as a systematic sampling design with an average sample coverage of 49.3 per cent. However, only basic statistical analyses were performed since the levels of significance between the various work methods were more or less apparent and since it was felt that a detailed statistical analysis would serve no real purpose.

To obtain the productive crushing time at each borrow pit in hours, the number of productive crushing process observations were summed for the periods over which the crusher was at each borrow pit and divided by 120. The total number of observations when the excavator was performing the landscaping (levelling and sloping the borrow pit after the material had been removed) and stripping (removing the surface organic layer and unusable soils) process, were also summed for each borrow pit and divided by 2 to obtain the time spent in minutes.

Regression analysis was used to determine the relationship between the landscaping and stripping time required and the productive crushing time at the borrow pit.

The time spent moving between each borrow pit and the distance of each move were determined. Regression analysis was used to determine the relationship between the actual moving time and the distance of the move. The total moving time was made up of the following phases: positioning at the borrow pit to start moving, actual moving between borrow pits and positioning at the next borrow pit before starting to crush. Based upon the derived regression equations, an equation was developed to calculate the theoretical working time required for various borrow pit spacings. This equation was expanded so it could be applied to calculate the theoretical working times required to complete a 1 000 m section of forest road, depending upon which borrow pit spacing was used.

Regression analysis was also used to determine the relationship between the spreading work cycle times of the Fiat 1000 DT Super tractor and the hauling distance for both groups of work cycle data. An equation was developed to enable the estimation of the critical hauling distance after which the crusher production rate exceeded the hauling and spreading rate.

Production analysis: The number of bucket-fulls of material fed to the crusher were summed on each observation sheet. The production rate was then calculated for each one-half hour time period studied for each method. The average productivity, standard deviation and 95 and 99 per cent confidence intervals were calculated for each method using total working time. The average productivity during productive crushing hours was also calculated. For method 4 the production was determined by measuring the volume of the stockpiles.

Cost analysis: Negotiated hourly rates were used for all the machines employed during the study. The total cost per hour for each method was determined. The cost per cubic metre of crushed material spread onto the road was calculated for each method. Road pavement construction costs were also calculated for a theoretical 1 000 m section of feeder forest road when employing the mobile crusher method and a conventional forest road construction method where road building materials must be hauled to the work site.

Table 1. Summary of the time study sample size: crusher and excavator data combined.
Taulukko 1. Yhteenveto työntutkimuksessa otetuista näytteistä: murskaimen ja kaivurin havainnot on laskettu yhteen.

Method (see p. 7) *Menetelmä (katso liite B)*	Total no. of observations *Havaintojen yhteismäärä, kpl*	Observation period, h *Seuranta-aika, h*	Total working time[1], h *Kokonaistyöaika[1], h*	Sampling coverage, % *Näytteiden peittävyys, %*
1-A	4 200	35.0	100.2	34.9
1-B	1 240	10.4	10.4	100.0
1-C	576	4.8	4.8	100.0
2-A	2 788	23.2	23.3	100.0
2-B	3 922	32.6	90.0	36.2
2-C	1 832	15.2	15.2	100.0
3	586	4.8	14.0	34.3
4	992	8.2	14.4	56.9
Total Yhteensä	16 136	134.2	272.2	49.3

[1] Based on the total tachometer time.
[1] Perustuu tärinäkellolla mitattuun aikaan.

24. Sample size

A summary of the time study sampling for the crusher and excavator data combined, is given in Table 1. The combined crusher and excavator working hours was 272.2 h. The actual combined time over which the machines were closely observed was 134.2 h. This resulted in a sampling coverage of 49.3 per cent. A total of 16 136 time study observations were made: observations for excavator and cursher combined.

3. RESULTS AND DISCUSSION

31. Time study

311. Crushing at roadside

The distributions for the crusher and excavator work processes for the various work methods when crushing occurred at roadside borrow pits are presented in Table 2 and Table 3.

Crusher: The overall productive crushing times for the various work methods were similar: the maximum was 69.6 per cent and the minimum was 63.6 per cent. For all the methods where the crushed material was deposited directly onto the hauling vehicles the time spent moving at the work site was minimal: the maximum was 1.4 per cent and the minimum was 0.7 per cent. For methods 2-A, 2-B and 2-C, as the spacing between the borrow pits decreased the time spent moving at the work site increased. The time spent moving at the work site was 2.3 per cent for borrow pit spacings from 150 to 500

Table 2. Crusher and excavator work process distributions when crushing at roadside borrow pits directly onto the hauling vehicles. Methods 1-A and 1-B employed two hauling vehicles, while method 1-C employed one.
Taulukko 2. Murskaimen ja kaivurin työaikalajien jakaantuminen murskattaessa tienvierikuopilta suoraan kuljetusajoneuvoihin. Menetelmissä 1-A ja 1-B käytössä kaksi ajoneuvoa, menetelmässä 1-C vain yksi.

Work processes — *Työjaksot*	Method[1] — *Menetelmä*[1] 1-A	1-B	1-C
	Work process distribution, % *Työjakson jakaantuminen, %*		
Crusher — *Murskain*			
Productive crushing time — *Tehoaika murskauksessa*	69.6	66.0	63.9
Moving at work site — *Liikkuminen työmaalla*	1.4	1.3	0.7
Crusher jammed — *Murskain tukossa*	6.5	5.3	9.3
Waiting for material — *Murskattavan materiaalin odotus*	10.4	4.4	5.9
Waiting for hauling equip. — *Ajokaluston odotusta*	11.4	3.2	20.2
Operator delay — *Koneen käyttäjän viivytys*	0.0	0.0	0.0
Excavator down — *Kaivuri rikki*	0.6	4.8	0.0
Crusher down — *Murskain rikki*	0.0	4.2	0.0
Maintenance & adjusting — *Huolto, säädöt*	0.0	0.8	0.0
Total delay time — *Koko viivytysaika*	28.9	32.7	35.4
Excavator — *Kaivuri*			
Digging — *Kaivu*	27.8	35.0	24.0
Swinging to feed — *Kääntö murskaimen syöttöön*	9.4	9.8	10.1
Feeding crusher — *Murskaimen syöttö*	8.2	12.7	9.4
Swing to dig — *Kääntö kaivuun*	6.6	9.4	9.7
Waiting to feed & after — *Odottaminen ennen syöttöä ja sen jälkeen*	17.2	3.9	7.2
Landscaping & stripping pit — *Pintakerroksen irroitus ja kuoppien tasaus*	14.7	21.5	12.0
Moving at work site — *Liikkuminen työmaalla*	2.9	1.8	7.3
Crusher jammed — *Murskain tukossa*	3.4	1.9	8.0
Waiting for hauling equip. — *Ajokaluston odotusta*	6.4	0.0	12.2
Operator delay — *Koneen käyttäjän viivytys*	0.0	0.0	0.0
Excavator down — *Kaivuri rikki*	1.3	2.1	0.0
Crusher down — *Murskain rikki*	0.0	1.9	0.0
Planning — *Suunnittelua*	2.1	0.0	0.0
Total delay time — *Koko viivytysaika*	13.2	5.9	20.2

[1] See p. 7
[1] *Katso liite B*

m and 6.7 per cent for 10 intervals. The effect of borrow pit spacing will be discussed in further detail in section 313. (p. 13).

For methods 1-A, 1-B and 1-C, the time lost due to over-sized rocks jamming the crusher head increased from 5.3 per cent for the largest feeding unit (RH-6), to 9.3 per cent for the smallest unit (Valtra UM-353-CM). Also, for the same feeding unit (Valtra UM-353-CM), as the distance between the borrow pits decreased the crushing time lost due to crusher head jamming increased. The increase was from 9.3 per cent when crushing directly onto the hauling vehicles at borrow pits fairly widely spaced (150 to 500 m), to 15.5 per cent for pits at 10 m intervals.

For all the work methods it appears that the time spent by the crusher waiting for material to crush increased with decrease in excavator capacity and increased with increased distance between borrow pits (i.e. the size of the roadside borrow pit). For methods 1-A, 1-B and 1-C, the time spent waiting for hauling equipment increased from a minimum of 3.2 per cent for method 1-B, which employed two hauling vehicles and the work site conditions facilitated easy vehicle turning, meeting and backing, to a total of 20.2 per cent for method 1-C which only employed one hauling vehicle and the work site conditions were poor (i.e. low standard feeder road).

The remaining delays could not be attributed to work method and were basically uncontrollable delays. Total delay times for the crusher ranged from 23.3 to 35.4 per cent. Generally, as the distance between the

Table 3. Crusher and excavator work process distributions when crushing occurred at roadside borrow pits at various spacings. The crushed material was dropped directly onto the road subgrade and a Fiat 1000 DT Super tractor equipped with a front bucket and grader blade was used to haul and spread the crushed material.
Taulukko 3. Murskaimen ja kaivurin työaikalajien jakaantuminen murskattaessa eri etäisyyksillä olevissa tienvierikuopissa. Murskattu materiaali pudotettiin suoraan tien rungolle, josta murske siirrettiin ja levitettiin etukuormaajalla ja lanalevyllä varustetulla Fiat 1000 DT Super traktorilla.

Work process — *Työjaksot*	Method[1] — *Menetelmä[1]* 2-A	2-B	2-C
	Work process distribution, % *Työjaksojen jakaantuminen, %*		
Crusher — *Murskain*			
Productive crushing time — *Tehoaika murskauksessa*	63.3	65.9	69.6
Moving at work site — *Liikkuminen työmaalla*	2.3	3.8	6.7
Crusher jammed — *Murskain tukossa*	11.3	14.1	15.5
Waiting for material — *Murskattavan aineen odotus*	16.4	13.0	5.2
Waiting for hauling equip. — *Ajokaluston odotusta*	0.0	0.0	0.0
Operator delay — *Koneen käyttäjän viivytys*	0.5	1.1	2.6
Excavator down — *Kaivuri rikki*	0.0	1.0	0.0
Crusher down — *Murskain rikki*	4.9	0.0	0.0
Maintenance & adjusting — *Huolto, säädöt*	1.0	0.6	0.4
Total delay time — *Koko viivytysaika*	34.1	30.3	23.7
Excavator — *Kaivuri*			
Digging — *Kaivu*	28.5	26.1	23.4
Swinging to feed — *Kääntö murskaimen syöttöön*	10.4	12.7	13.1
Feeding crusher — *Murskaimen syöttö*	8.2	6.9	8.9
Swinging to dig — *Kääntö kaivuun*	7.9	8.5	8.3
Waiting to feed & after — *Odottaminen ennen syöttöä ja sen jälkeen*	10.8	10.4	15.7
Landscaping & stripping pit — *Pintakerroksen irroitus ja kuoppien tasaus*	17.6	16.3	11.2
Moving at work site — *Liikkuminen työmaalla*	3.3	8.9	10.1
Crusher jammed — *Murskain tukossa*	6.7	8.8	8.0
Waiting for hauling equip. — *Ajokaluston odotusta*	0.0	0.0	0.0
Operator delay — *Koneen käyttäjän viivytys*	0.5	0.0	0.1
Excavator down — *Kaivuri rikki*	1.9	1.0	0.0
Crusher down — *Murskain rikki*	3.7	0.0	0.0
Planning — *Suunnittelua*	0.5	0.4	1.2
Total delay time — *Koko viivytysaika*	13.3	10.2	9.3

[1] See p. 7
[1] Katso liite B

borrow pits increased the total delay time also increased. Also, excluding mechanical delays, as the size of the feeding unit (i.e. excavator capacity) increased the total delay time decreased. The crusher operator was the same throughout the study and thus there was no operator effect. All the excavator operators were very experienced and thus the excavator operator effect would seem to be minimal. Quite apparent, however, is that operator skill comes more into question with smaller feeding units.

Excavator: As the excavator capacity increased the time spent during the digging process increased. For the RH-6, 35 per cent of the time was spent digging while only, on the average, 25.5 per cent of the time was spend digging by the Valtra UM-353-CM. The digging difficulty also had an effect on the time spent digging. Generally, similar times were spent during the crusher feeding process (swinging to feed, feeding and swing to dig) by both the RH-6 and the Valtra UM-353-CM: 28.1 and 28.9 per cent respectively. The value obtained for the Valtra UM-353-CM is the average value obtained for methods 1-C, 2-A, 2-B and 2-C. The total time spent during the feeding process by the Brøyt X-20 was slightly less: 24.2 per cent. There was no clear trend apparent for the per cent of the time spent waiting to feed and after feeding the crusher.

Generally, as the distance between borrow pits increased and the crushing time at the borrow pit increased, the time required for landscaping and stripping the borrow pit also increased. This will be further discussed in section 313.

As the size of the excavator increased the delay time due to crusher head jamming decreased. No trend was apparent of the

Table 4. Crusher and excavator work process distributions when crushing occurred in fairly large gravel pits. Work site conditions were classed as excellent.
Taulukko 4. Murskaimen ja kaivurin työaikalajien jakaantuminen, kun murskaus tapahtui suhteellisen isoilla sorakuopilla. Työpaikkaolosuhteet luokiteltu erinomaisiksi.

Work processes — *Työjaksot*	Method[1] — *Menetelmä[1]* 3	4
	Work process distribution, % / *Työjaksojen jakaantuminen, %*	
Crusher — *Murskain*		
Productive crushing time — *Tehoaika murskauksessa*	89.5	94.0
Moving at work site — *Liikkuminen työmaalla*	2.0	0.4
Crusher jammed — *Murskain tukossa*	1.7	4.0
Waiting for material — *Murskattavan aineen odotus*	0.0	0.2
Waiting for hauling equip. — *Ajokaluston odotusta*	6.8	0.0
Operator delay — *Koneen käyttäjän viivytys*	0.0	0.0
Excavator down — *Kaivuri rikki*	0.0	0.0
Crusher down — *Murskain rikki*	0.0	0.0
Maintenance & adjusting — *Huolto, säädöt*	0.0	1.1
Total delay time — *Koko viivytysaika*	8.5	5.6
Excavator — *Kaivuri*		
Digging — *Kaivu*	30.0	13.8
Swinging to feed — *Kääntö murskaimen syöttöön*	20.5	11.1
Feeding crusher — *Murskaimen syöttö*	21.8	7.1
Swing to dig — *Kääntö kaivuun*	13.7	7.1
Waiting to feed & after — *Odottaminen ennen syöttöä ja sen jälkeen*	4.1	48.2
Landscaping & stripping pit — *Pintakerroksen irroitus ja kuoppien tasaus*	8.9	9.9
Moving at work site — *Liikkuminen työmaalla*	1.0	1.8
Crusher jammed — *Murskain tukossa*	0.0	1.0
Waiting for hauling equip. — *Ajokaluston odotusta*	0.0	0.0
Operator delay — *Koneen käyttäjän viivytys*	0.0	0.0
Excavator down — *Kaivuri rikki*	0.0	0.0
Crusher down — *Murskain rikki*	0.0	0.0
Planning — *Suunnittelua*	0.0	0.0
Total delay time — *Koko viivytysaika*	0.0	1.0

[1] See p. 7
[1] Katso liite B

effect of borrow pit spacing on the excavator waiting time due to crusher head jamming. When the number of hauling vehicles was reduced from two to one, the time spent waiting for the hauling vehicle doubled under similar work site conditions.

The remaining delay times could not be controlled to any extent by work method. Generally, as the size of the excavator increased, the total delay time decreased. Also, as the distance between the borrow pits increased the total excavator delay time increased.

Hauling vehicles: Generally, for two 5 m^3 capacity hauling vehicles and a crusher production rate of 23.0 m^3/h, each hauling vehicle would spend approximately 48 per cent of the time getting loaded, 18 per cent of the time away spreading, 30 per cent of the time waiting and 4 per cent of the time positioning to get loaded. However, the proportion of the time spent between dumping and waiting would also depend upon the road construction site conditions and the distance the material was hauled. The effect of the number of hauling vehicles will be more apparent in the cost analysis (section 33., p. 18).

312. Crushing in a gravel pit

The work process distributions for the work methods when crushing occurred in gravel pits are presented in Table 4. As can be seen, there was little delay time. For method 3, the majority of the delay time was attributed to waiting for the hauling equipment to position themselves under the crusher to get loaded. Time spent waiting for the hauling equipment in method 3 was 2.1 times the value obtained in method 1-B. However, the production rate of method 3 was double the rate obtained for method 1-B. For both methods 3 and 4, the maximum crusher capacity for the top size of material produced was more or less reached. Total crusher delay times for method 3 and 4 were 8.5 and 5.6 per cent respectively. The total delay times for the excavators were 0.0 and 1.0 per cent for methods 3 and 4 respectively.

313. Moving between borrow pits

The effect of the productive crushing time at a borrow pit on the time required to strip and landscape the pit is shown in Fig. 2. The effect of the moving distance on the actual time required to move is shown in Fig. 3 (p. 14).

The productive crushing time at a borrow pit is a function of the distance between the pits. As can be seen from Fig. 2, the time required for stripping and landscaping a borrow pit increased at a decreasing rate until approximately 2.5 h of productive crushing time at the pit. After 2.5 h of crushing, the time required for stripping and landscaping accelerated. For the actual moving time required for various distances of move, the rate of increase decreased continuously. For a move of 1 750 m, the time required to move was 25.8 min. This would be an average speed of 4.1 km/h. For a 100 m move a total of 3.2 min was required: resulting in an average speed of 1.9 km/h. The above speeds were for moves at the same work site. These values are considerably lower than the average speed of 6 km/h given for moves at the work site by

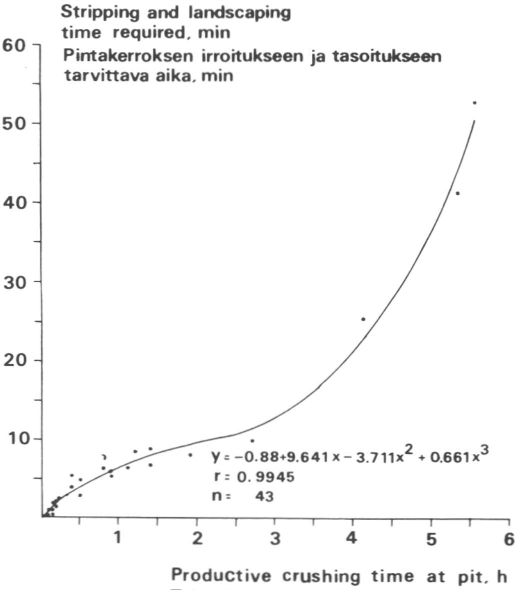

Fig. 2. The effect of productive crushing time at a borrow pit on the time required to strip and landscape the pit.
Kuva 2. Tehokkaan murskausajan vaikutus moreeninottokuopalla verrattuna pintakerroksen poistoon ja kuopan jälkitasoitteluun.

Ylä-Hemmilä (1978). On a good quality municipal road the average speed obtained by the crusher was 10 km/h. Ylä-Hemmilä (1978), however, stated that speeds of up to 19 km/h have been reached with the crusher when moving between work sites. This would only be possible on high standard roads since the bounce of the machine would otherwise make driving it quite hazardous.

For the forest roads constructed during this study the average thickness of the pavement layer composed of crushed material was 10 cm (s = ±4.15, n = 130). The average width of the travel surface was 3.0 m (s = ± 0.48, n = 165). Therefore, approximately 0,3 m^3 of crushed material was used for each metre of road length. The forest roads built were classed as low standard feeder roads. The average productivity per productive crushing hour for the various methods employed at roadside was 34.6 m^3/h (Table 5, p. 17). Therefore, for this study the theoretical spacing for the various productive crushing times at a borrow pit is given by the following equation:

$$S = 115.3 \cdot T_{ph}, \tag{1}$$

where, S is the borrow pit spacing in metres and T_{ph} is the productive crushing time at the pit in hours.

This equation is applicable for productive crushing time and not for total working time at the borrow pit.

To calculate the theoretical crushing time required for various borrow pit spacings the following equations were developed:

$$T_{tm} = T_{pm} + T_{sl} + T_{mm}, \tag{2}$$

$$T_{tm} = 0.244 + 0.625 \cdot D - 0.000283 \cdot D^2 + 0.00000043 \cdot D^3, \tag{3}$$

where, T_{tm} is the total theoretical working time required to complete the road section between the borrow pits,
T_{pm} is the total productive crushing time in minutes,
T_{sl} is the time required for stripping and landscaping in minutes,
T_{mm} is the time required to move between the borrow pits in minutes and
D is the distance between the borrow pits in metres.

To calculate the theoretical time required to complete a 1 000 m section of low standard feeder forest road, equation 3 was further developed:

$$T_{1000} = (0.244 + 0.625 \cdot D - 0.000283 \cdot D^2 + 0.00000043 \cdot D^3)(1\,000/D), \tag{4}$$

where, T_{1000} is the theoretical time, in minutes, required to complete a 1 000 m section of low class feeder forest road.

Using equation 4 the theoretical times required to complete a 1 000 m section of low standard feeder road, using various borrow pit spacings, were calculated and are graphed in Fig. 4.

However, the values calculated do not consider the cost of hauling the crushed material and this will be covered in section 314. As can be seen from Fig. 4, the optimum spacing, excluding the effect of hauling costs, would be approximately 332 m. The effect of borrow pit spacing was minimal within the range of 50 to 620 m: the increase in crushing work time was only 6.5

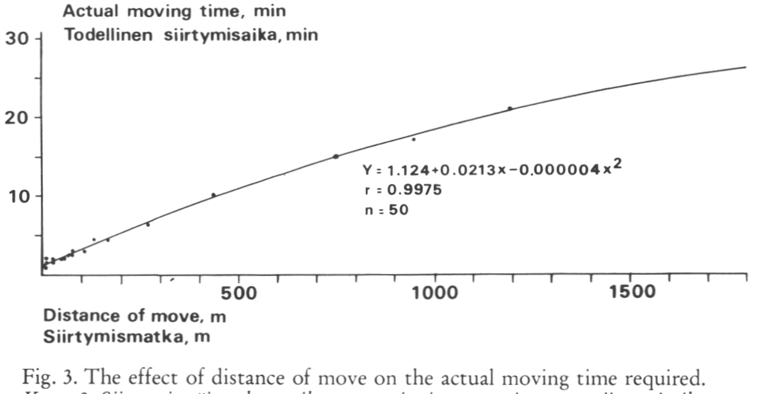

Fig. 3. The effect of distance of move on the actual moving time required.
Kuva 3. Siirtymisetäisyyden vaikutus varsinaiseen tarvittavaan siirtymisaikaan.

per cent at the limits of the range. Spacings less than 50 m and greater than 620 m resulted in a large acceleration in the work time required. The increase was more significant at denser spacings than at wider spacings. Therefore, it appears that it is wiser to make the spacing between the borrow pits too long rather than too short when only taking into account the crusher and excavator work time required.

314. Hauling

When crushing directly onto the hauling equipment and assuming that the average crushing rate at roadside was 23.0 m^3/h, the time required to crush a 6 m^3 load would be 15.7 min. It was found from the time study that even under excellent conditions the loss of productive crushing time due to waiting for the hauling vehicles to position under the crusher, was 3.2 per cent. Crushing under unfavourable conditions the time lost due to waiting for the hauling equipment was 11.4 per cent. It was also apparent from the time study data, that if long hauling distances are involved, at least two hauling vehicles should be used. From the time study data for method 1-C, the time lost

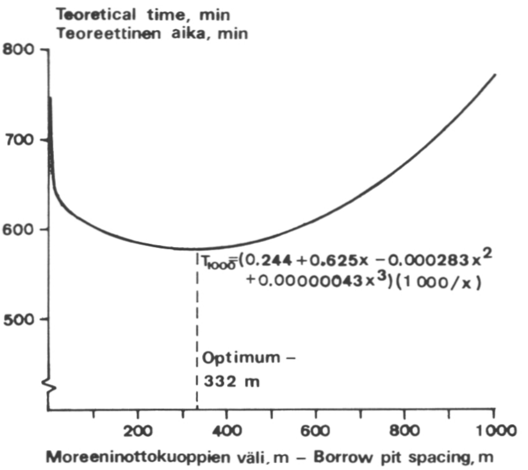

Fig. 4. The effect of borrow pit spacing on the theoretical time required to complete a 1 000 m section of low standard feeder forest road employing work method 2.

Kuva 4. Moreeninottokuoppien välien vaikutus teoreettiseen aikaan, joka tarvitaan 1 000 m:n matalatasoisen metsäautotien tieosuuden tekemiseen käytettäessä työmenetelmää 2.

due to waiting for the hauling equipment was 20.2 per cent: only one hauling vehicle was employed and the average hauling distance was 150 m. Roughly calculated, the cost of not employing another hauling vehicle, due to lost productive time when the crusher and the excavator were idle, was 67.67 FIM/h (1979 costs). This assumes a crusher plus excavator hourly cost of 335 FIM. This figure is slightly above the cost of employing an additional hauling vehicle which would have been approximately 65 FIM/h (1979 costs). Therefore, it appears that two hauling vehicles would be required for crushing operations where the borrow pit spacing is close to or greater than the optimal 332 m specified in section 313.

For shorter hauling distances one hauling vehicle can be used. It is also apparent that for shorter haul distances a wheeled front-end loader would be more applicable than a dump-box equipped vehicle. No accurate estimate could be made as to the hauling distance at which one or two hauling vehicles should be employed.

In methods 2-A, 2-B and 2-C, the material was crushed directly onto the road subgrade and then spread by a Fiat 1000 DT Super tractor equipped with front loader and grader blade. The effect of the hauling distance on the time required to complete the hauling work cycles of (A) load — haul — spread — grade — return and (B) load — haul — dump — return, is presented in Fig. 5. (p. 16).

As can be seen high correlation coefficients were obtained for both regression equations. The proportion of occurrence of the two work cycles to each other was 14 to 24 for work cycles (A) to (B). From Fig. 5, it can also be seen that work cycle (A) had a cubic function and as the hauling distance increased the increase in the time required decreased. From the data obtained it is felt that the curve is only applicable up to a hauling distance of 70 to 75 m since there was only one work cycle (A) observation over 70 m. For work cycle (B) the relationship between the total cycle time and hauling distance was linear. From the observations, the total hauling and spreading time for the construction of the 100 m section of road was calculated using both types of work cycle: 25.8 min were spent performing (A) and 29.2 min were spent performing (B). Therefore, a total of 55 min were required to spread the material onto the section of road. A total of 38 bucket-fulls of material were hauled and each bucket-full was approximately 700 l. Therefore, approximately 26.6 m^3 of crushed material were spread over the 55 min period. It was also recorded that the haul vehicle was just able to keep up with the crusher. If the crusher production would have been higher or the hauling distance longer, the hauling vehicle would not have been able to keep up. These observations, however, are for only one section of road and further studying would be required to obtain an accurate view of the situation.

Since the average crusher production per working hour, while crushing during methods 2-A, 2-B and 2-C, was approximately 22.7 m^3/h and since, on the average, approximately 0.3 m^3 of crushed material was applied per running metre of low standard feeder forest road, an approximation of the average hauling distance at which the crusher production would exceed the hauling and spreading production was made using the following equation:

$$T_s = 12.9 + 1.0545 \cdot D - 0.00597 \cdot D^2 + 0.000012 \cdot D^3, \quad (5)$$

where, T_s is the time required by the Fiat tractor to haul and spread 22.7 m^3 of crushed material and

D is the average hauling distance.

Equation 5 was derived by combing the regression equations given in Fig. 5 in proportion to their frequency of occurrence. The average distance at which the required hauling and spreading work time is equal to 60 min would be the critical distance where the hauling vehicle production equals the crusher production.

For the section of road studied the actual total length was 102 m (average 51 m). Substituting this value into equation 5 we get 53 min. This value indicates that the production of the hauling vehicle was slightly higher than the production of the crusher. From the actual field observations it was also found that this was the case.

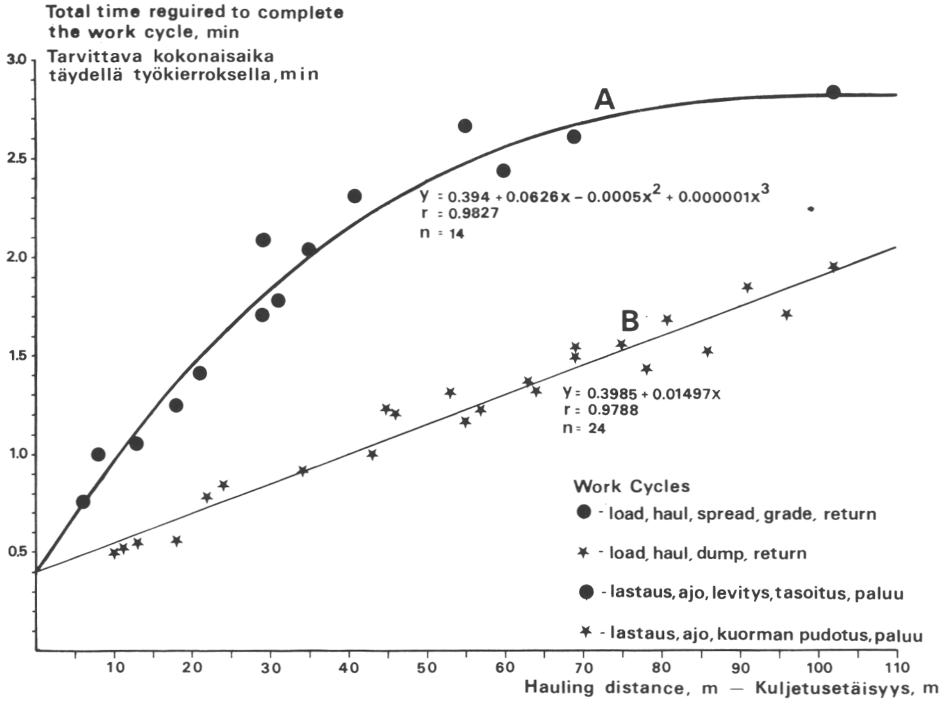

Fig. 5. The effect of hauling distance on the total time required to complete two types of hauling work cycle for a 100 m section of a low standard feeder forest road.
Kuva 5. Kuljetusetäisyyden vaikutus kuljetustyökierroksen kokonaisaikaan rakennettaessa 100 m matalatasoista metsäautotietä. Kierrostyypit A ja B.

A computer simulation was used to find the average distance where the hauling production equalled the crusher production: this was at 75 m. This indicates that a borrow pit spacing of approximately 150 m would be the critical spacing for the Fiat 1000 DT Super tractor. Although many assumptions have been made in calculating the critical distance, it is felt that it gives a realistic value when compared to the hauling and spreading observations made during this study. It should also be noted that this value is only applicable to the Fiat tractor studied.

Greater production rates and therefore wider borrow pit spacings can probably be achieved by employing larger front-end loaders. However, the additional cost of employing larger equipment may offset the benefit drived from the increased hauling capacity. The above factors need to be studied further in future reports. The good feature of the Fiat DT 1000 DT Super tractor was that while returning to load it could also grade the road surface. This eliminated the need for an additional piece of equipment for grading and thus reduced the total road construction cost.

Method 4 of this study was used for crushing in a gravel pit and for spreading the material at a later date when convenient. For hauling and spreading the Fiat 1000 DT Super tractor equipped with a dump box was used. The spreading work was performed on two sections of forest road where the average hauling distances for the first and second sections were 400 and 1 250 m respectively. 100 m^3 of crushed material was spread over the first section, while 55 m^3 were spread over the second. No work study information was collected for this operation. Cost data was obtained and are presented in section 33 (p. 18).

32. Production

A summary of the production rates for the crushing methods studied is given in Table 5. All the production rates for the methods at roadside were very similar. Method 4 had the lowest production rate of all the methods. This was due to the small top size of the crushed material produced. In order to allow easier comparison of the production rates for the various crushing methods, the 95 and 99 per cent confidence intervals were calculated and are presented in Table 6 (p. 18). As can be seen from Table 6, the variation of the production rates within each method was very small. For all methods the confidence interval maximum at even the 99 per cent level was only 8.3 per cent of the mean (method 1-B), while the minimum was 0.8 per cent of the mean (method 2-A). The average production for method 3 was considerably higher than the production for all the other methods. Method 1-C had the lowest productivity of the methods where crushing occurred at roadside, while method 2-A had the second lowest. Methods 1-A and 1-B had the highest productivities of the methods at roadside.

Table 5. Production summary for the crushing methods studied.
Taulukko 5. Tuotosyhdistelmä käytetyistä murskausmenetelmistä.

Method (see p. 7) *Menetelmä (katso liite B)*	Crushed moraine top size, mm *Suurin murskekoko, mm*	Average productivity, m^3/h *Keskimääränen tuotos, m^3/h*		s[1], ± m^3/h
		Total working time *Kokonais-työmaa-aika*	Productive working time *Tehollinen työmaa-aika*	
1-A	55—60	24.4	35.1	3.13
1-B	55—60	23.6	35.8	3.26
1-C	55—60	21.8	34.1	3.18
2-A	55—60	22.2	34.9	1.93
2-B	55—60	22.8	34.6	3.24
2-C	55—60	23.0	33.0	2.63
3	55—60	47.3	52.8	6.29
4	28—33	19.8	21.1	--

[1] Standard deviation for total working time productivity.
[1] *Kokonaistyömaa-ajan tuotoksen keskihajonta.*

Table 6. Confidence intervals (CI) for the average production rates (total working time) of the various crushing methods.
Taulukko 6. Työmaa-ajan keskituotosarvojen luotettavuusvälit (CI) eri murskausmenetelmissä.

Method (see p. 7) *Menetelmä (katso liite B)*	Average productivity for total working time, m³/h *Työmaa-ajan keskimääräinen tuotos, m³/h*	Confidence intervals, ± m³/h *Luotettavuusvälit, = m³/h* 95 %	99 %
1-A	24.4	0.69	0.91
1-B	23.6	1.44	1.95
1-C	21.8	0.43	0.56
2-A	22.2	0.13	0.18
2-B	22.8	0.17	0.24
2-C	23.0	0.19	0.25
3	47.3	2.71	3.68
4	19.8	--	--

Table 7. Hourly rates for the machinery employed during the study (1979 rates).
Taulukko 7. Tutkimuksen aikana käytettyjen koneiden tuntitaksat (1979 taksat).

Machine type — *Konetyyppi*	Rate[1], FIM/h
Mertsa mobile moraine crusher *Liikkuva Mertsa murskain*	250
Excavators — *Kaivukoneet*	
— Brøyt X-20	115
— RH-6[2]	85
— Valtra UM-353-CM	85
Fiat 1000 DT Super tractor/*traktori*	70
McCormick International 434 tractor/ *traktori* (2.5 m³ cap.)	50
Jyry Sisu truck/*kuorma-auto* (6 m³ cap.)	65
Sisu truck/*kuorma-auto* (5 m³ cap.)	50
Volvo N-86 truck/*kuorma-auto* (6 m³ cap.)	63
Lokomo grader/*tiehöylä* (12 t)	122

1 All the hourly rates include the wages and fringe benefit costs of the operator.
1 Kaikkiin tuntitaksoihin sisältyvät myös kuljettajan palkat sekä erityislisät.
2 The actual hourly rate for an excavator of this size is 135 FIM/h, however, the rate negotiated for the particular contract was only 85 FIM/h.
2 Tätä kokoa olevan kaivukoneen varsinainen tuntitaksa on 135 FIM/h. Kuitenkin tässä tapauksessa tuntitaksaksi oli sovittu 85 FIM/h.

33. Cost analysis

The hourly rates for the various pieces of equipment employed during the study are presented in Table 7. The rates given in the table are 1979 rates. The rates employed for the Mertsa mobile moraine crusher, the three excavators, the Fiat 1000 DT Super tractor and the McCormick International tractor were negotiated rates made between the employer and the contractors. The rates for the gravel trucks and the grader were based on standard rates employed by the National Board of Roads and Waterways (TVL) for rural, remote work sites. Since the study was done during 1979, the rates are in 1979 FIM. All the cost analyses assume that the cost of the moraine to be crushed is zero.

By employing the hourly rates given in Table 7 and the production rates given in Table 5 (p. 17), the cost per cubic metre of crushed material spread onto the road was calculated for each method (Table 8).

As can be seen, method 3 had the lowest unit cost. This was due to the high production rate of the method, which was at least double the production rate of the other methods; with the exception of method 1-A where the production rate for method 3 was 1.9 times greater. Of the methods where crushing occurred at roadside, method 2-C had the lowest unit cost. For the methods where crushing occurred at roadside, as the cost of the excavator increased so did the cost of the crushed product. As the cost of the hauling vehicles employed increased, so did the cost of the crushed product.

Method 4 had the second highest unit cost of all the methods. The major factor influencing the high cost of the crushed product was the low production rate due to the small product top size: 28 to 33 mm as compared to 55 to 66 mm for the other methods. By substituting the production rate obtained in method 3 for the production rate of method 4, the cost of the crushed product spread onto the road would be 13.20 FIM/m³. Therefore, when accounting for product top size, both methods 3 and 4 had more or less the same unit cost. The average hauling distance for method 4 was approximately 700 m. For method 3 it was 500 m. Therefore, a lower material cost could have possibly been achieved when employing method 4 if the hauling distances had been equal and the product top size the same.

Method 1-B had the highest unit cost of all the methods. This result emphasises the inappropriateness of employing large complex crushing — hauling systems at roadside in forest road construction due to the low crushing rates which can be expected.

To obtain a theoretical cost comparison between the cost of building a road pavement employing the mobile crusher method and another, employing a conventional method where gravel must be hauled to the work site from various distances, cost calculations were made for a theoretical 1 000 m section of feeder forest road. In the calculations the costs of subgrade preparation and road drainage were omitted and only the cost of forming the road pavement dealt with. It was assumed that for hauling gravel the purchase price of the gravel was 1.00 FIM/m^3: the cost of the moraine material to be crushed was assumed to be 0. It was also assumed that the cost of loading the gravel was 2.50 FIM/m^3 and that the cost of spreading and grading the material on the road surface was 2.50 FIM/m^3. All the above costs are in 1979 FIM. At large road construction work sites, where the quantities of material required are large, the effect of economy of scale would result in lower loading, spreading and grading costs. The hauling rates used were based on the rural gravel hauling rates which the TVL used for their own work sites in remote rural conditions (1979).

From the road cross-sections it was found that the average quantity of crushed material used per running metre of road was 0.3 m^3. Standards drawn up by the National Board of Forestry specify that a pavement thickness of 15 cm is required for a subgrade bearing class of "C". It was estimated that the subgrade class on which the crushed moraine was laid was of class "C". Following the above specified norm, a total of 0.45 m^3 of gravel would have been required per running metre of road. Pulkki (1980) found that on the average 45 per cent less crushed material, in regard to gravel, was required to obtain the same bearing capacity achieved with conventional road construction

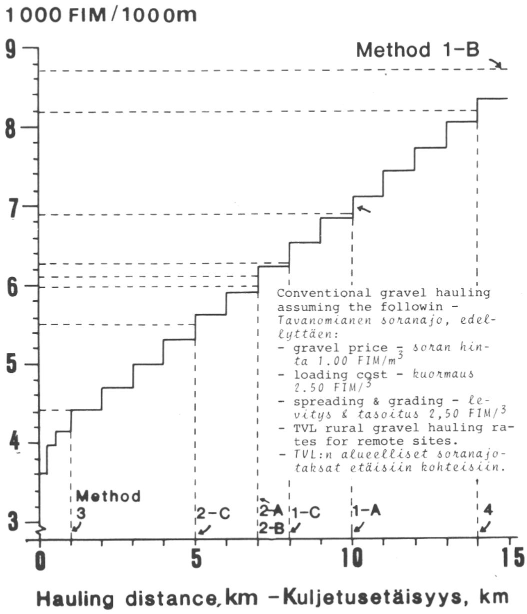

Fig. 6. Comparison of road pavement costs: when employing the mobile crusher method (assuming 25 per cent less material required) or conventional gravel hauling for various distances (1979 costs).

Kuva 6. Tien päällystämiskustannusten vertailua: käytettäessä liikkuvan murskaimen menetelmää (olettaen että materiaalin tarve on 25 % pienempi) tai tavanomaista soranajoa eri etäisyyksille (1979 kustannukset).

Table 8. Costs per cubic metre of crushed material spread onto the road by the various crushing methods employed (1979 costs). The moraine material costs was assumed to be 0.

Taulukko 8. Tielle levitetyn murskeen kuutiometrikustannukset käytettäessä eri murskausmenetelmiä (1979 kustannukset). Moreenimateriaalin hinta 0.

Method (see p. 7) *Menetelmä (katso liite B)*	Crushed material cost, FIM/m^3 *Murskekustannukset, FIM/m^3*	Spreading cost if applicable[1], FIM/m^3 *Levityskustannukset mikäli käytettävissä, FIM/m^3*	Total cost, FIM/m^3 *Kokonaiskustannukset, FIM/m^3*
1-A	20.42	--	20.42
1-B	21.19	5.17	26.36
1-C	18.58	--	18.58
2-A	18.24	--	18.24
2-B	17.76	--	17.76
2-C	14.57	1.80	16.37
3	10.57	2.58	13.15
4	18.43	5.85	24.28

[1] The cost of spreading the material by a special grader machine (i.e. a medium class grader in methods 1-B and 3), or hauling and spreading the material as a separate function from the initial crushing work (i.e. methods 2-C and 4).

[1] Murskeen levityskustannukset erityisellä tasoituskoneella (so. keskiraskaalla tiehöylällä menetelmissä 1-B ja 3) tai murskemateriaalin ajo ja levitys erillisenä toimintana murskaustyön jälkeen (so. menetelmät 2-C ja 4).

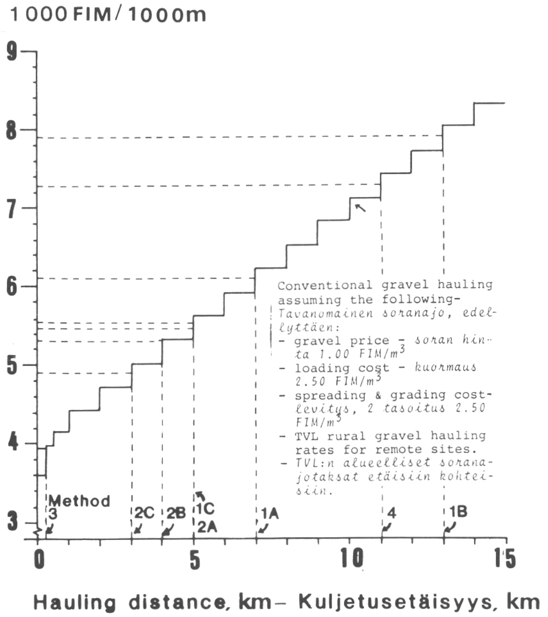

Fig. 7. Comparison of road pavement costs: when employing the mobile crusher method (assuming 33 per cent less material required) or conventional gravel hauling for various distances (1979 costs).

Kuva 7. Tien päällystämiskustannusten vertailua: käytettäessä liikkuvan murskaimen menetelmää (olettaen että materiaalin tarve on 33 % pienempi) tai tavanomaista soranajoa eri etäisyyksille (1979 kustannukset).

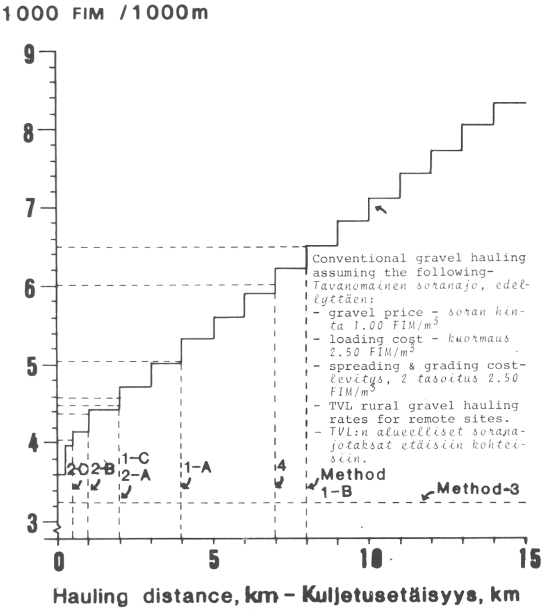

Fig. 8. Comparison of road pavement costs: when employing the mobile crusher method (assuming 45 per cent less material required) or conventional gravel hauling for various distances (1979 costs).

Kuva 8. Tien päällystämiskustannusten vertailua: käytettäessä liikkuvan murskaimen menetelmää (olettaen että materiaalin tarve on 45 % pienempi) tai tavanomaista soranajoa eri etäisyyksille (1979 kustannukset).

materials. It was also found that crushed moraine had at least 25 per cent more bearing strength than conventional road construction materials 95 per cent of the time. Therefore, cost comparison calculations were made for situations where 25, 33 and 45 per cent less crushed material would be required per metre of road when compared to conventional road construction materials (Fig. 6 (p. 19), 7 and 8).

As can be seen from Fig. 6, the road pavement cost when using crushed moraine and methods 2 and 3 was cheaper in all cases if the gravel had to be hauled for more than 7 km. If the topsize of the material produced in method 4 had been similar to that of the other methods a road pavement cost comparable to method 3 could have been expected. It should also be noted that the cost curve for the convential road construction pavement is not an absolute curve and is subject to variation according to the loading, spreading and grading costs, as well as the purchase price of the gravel applicable to each situation. Based on the results obtained in this study it can be safely said that by employing improved mobile crusher work techniques and by obtaining the maximum benefit from the increased quality of crushed moraine, crushing at or within the immediate vicinity of the road construction work site would result in lower feeder road construction costs if the gravel hauling distance is over 1 km. To obtain the maximum benefit from the crusher, the work method most applicable to the situation should be planned well in advance of the actual work.

For higher standard roads, where the quantities of material required is much larger, other types of crushing sytems (e.g. small to middle class semi-portable crushing plants) may be more applicable (Fig. 9). The gravel hauling distance at which crushing is cheaper would also probably vary. However, it is felt that in general, the same assumptions are applicable to larger operations. For example, at a TVL work

Fig. 9. A view of the Sorri crusher.
Kuva 9. Kuva Sorri-murskaimesta.

site near Mäntsälä during 13.8...20.10.1979, it was calculated that a total road construction saving of 22.5 per cent was made by employing the Mertsa mobile moraine crusher system (Tie- ja vesirakennuslaitos 1980).

4. CONCLUSIONS

41. General

By performing a continuous survey of the work methods an accurate account of the work processes was obtained. The interrelations between the work processes and machinery, and their effect on the productivity were also determinable. Although the time study results obtained for the crusher and excavator were based on a limited observation period of 134.2 h (crusher study hours and excavator study hours combined), is was felt that the results could be used to suggest the best work methods and recommend refinements to the present work methods employed and to the crusher itself.

The effect of operator performance was not examined. In this study it was assumed to be minimal since the crusher had the same operator throughout and since the excavator operators were all skillful (subjective judgement) and experienced. From the general study results it would seem that operator skill would have more significance with smaller feeding units.

42. Crushing at roadside

From the time study it was apparent that when crushing at roadside the borrow pits should be spaced close enough to allow the use of a crushing method where the crushed material is dropped directly onto the road subgrade and a front-end loader type machine used to spread the material. It was also found that by increasing the size of the machinery and by increasing the complexity of the work method, the cost of the crushed material was also increased. This was due to the higher hourly operating costs and the fixed production rate of the crusher, which is more or less uninfluenced by large complex feeding and hauling systems. By employing simple methods the mobile crusher system is very flexible and easy to adapt to varying work site conditions.

The maximum production rate of small-sized portable jaw crushers, where both large and small diameter particles pass through the crusher head, the work site conditions are excellent, a coarse dry material is crushed and the top size of the crushed product is from 55 to 66 mm, can be expected to be approximately 55 m^3/h. In roadside working conditions the maximum crusher production can be expected to be approximately 40 m^3/h, where both fine and coarse material is fed into the crusher head. Therefore, feeding and hauling capacities greater than that of the crusher are not required and would only result in excessive operating costs.

From the time study analysis it was found that a borrow pit spacing of 332 m was the optimum at which the excavator time required for stripping and landscaping the borrow pits and for moving at the work site was minimized. However, the increase in lost productive crushing time with deviation from the optimum was not too severe and thus allowed for a very wide variation in borrow pit spacing with minimal financial consequences. At borrow pit spacings less than 50 m, the productive crushing time loss escalated rapidly. Therefore, the borrow pit spacing should be selected so it is greater than 50 m but less than the point where the crusher production exceeds the hauling and spreading capacity. To allow for system flexibility, the hauling and spreading capacity should be slightly higher than the crusher production capacity.

Since crushing methods similar to method 2 were recommended when crushing at roadside, the maximum borrow pit spacing should be slightly less than 332 m. For the Fiat 1000 DT Super tractor the maximum distance was slightly below 150 m. The cost effect of the distance between borrow pits from 50 to 150 m was minimal: from the time study results, the cost actually decreased slightly with decrease in borrow pit spacing. However, this decrease in cost was not due to increased efficiency resulting from the reduced spacing, but was due to the difference in unavoidable delays and excavating difficulty between the methods. Large capacity front-end loaders compete well with other hauling methods up to distances of about 300 m (Antola 1979). They are therefore more applicable for wider borrow pit spacings than the small capacity Fiat used in this study. Therefore, when crushing directly onto the road subgrade and a wheeled front-end loader is continuously present, borrow pit spacings from 50 to a maximum of about 300 m are recommended, depending upon the work site conditions and the capacity of the front-end loader employed.

Of the methods where crushing occurred at roadside, the lowest crushed material cost was obtained when crushing occurred directly onto the road subgrade and the spreading occurred at a later date. When emloying this method excessive material may be crushed and thus result in a higher cost for the road section. Care must also be taken that the piles of crushed material are not made too large. The width of the stockpile base should not be greater than the desired width of the road. To allow for larger stockpiles, the borrow pits could be located at the road sections which are built for vehicle meeting. Since forest roads are generally single lane, special dual lane road section of about 50 m in length, should be built every 300 to 400 m to allow the haul trucks to meet and thus ease traffic flow.

43. Crushing in gravel pits

The lowest material costs obtained during this study were when crushing occurred in abandoned gravel pits. Since material unsuitable for road construction was crushed, the cost for the material was 0. In other situations there may be some charge for the low quality (very stoney) gravel however. Taking into account the difference in top size of the crushed product, similar costs would have been obtained when crushing occurred directly onto the hauling equipment or onto the ground for later hauling and spreading. When crushing in gravel pits the maximized crusher production was due to easy excavating, allowing maximum excavator production, and the dry coarse crush material. However, employing this method would require the presence of abandoned gravel pits and a hauling distance from the pit to the road site which is not excessive: based on the TVL gravel hauling rates for remote rural road construction sites, the hauling distance from the gravel pit crushing site should not be greater than 8 to 9 km, if crushing can be done at roadside. If the roadside crushing production rate could be increased from what it was during this study the above hauling margin would be reduced and thus make roadside crushing more attractive.

44. Crushing in relation to gravel hauling

Cost savings accrue in two ways when employing the mobile crusher method. The first is by reducing or eliminating the hauling distance. The second results from the reduction in the quantity of material required for the road pavement due to the increased bearing strength quality of the crushed moraine (as compared to gravel). When comparing the conventional road construction method, where high quality gravel must be hauled to the work site, with the mobile crusher method, it was apparent that the crusher method resulted in lower road pavement costs whenever the gravel hauling distance was over 7 km. By employing the most efficient crushing method effectively, so that maximum benefit was obtained, it was apparent that hauling gravel resulted in higher road pavement costs whenever the hauling distance was over 1 km.

The estimated road pavement costs assumed that the price of the hauled gravel was 1.00 FIM/m^3, the cost of loading the gravel was 2.50 FIM/m^3 and the cost of spreading and grading the material on the road surface was 2.50 FIM/m^3. For large size operations where the quantities of material required would be much larger, other types of crushing systems (e.g. semi-portable crushing plants) may be more applicable. The gravel hauling distance at which crushing is cheaper would also probably be reduced.

45. Improvements

For the crushing methods where crushing occurred at roadside, productive crushing time lost due to over-sized rocks jamming the crusher head, on the average, was 10.3 per cent. If the productivity could be increased by 10.3 per cent and the cost of the system was 405 FIM/h, a reduction of 2.33 FIM/m^3 in the cost of the crushed material could be achieved. This would be equal to a cost reduction of 13.2 per cent per m^3. To eliminate productive crushing time loss due to over-sized rocks, sloping steel beams, with a spacing no larger than the maximum particle size accepted by the crusher head, should be placed over the basin where the crushed material is fed onto the feed conveyor by the excavator. Therefore, all over-sized rocks would roll off to the side of the crusher from where they could be moved back into the borrow pit and buried.

To minimize crusher wear and to increase crusher production, a vibrating steel screen should be employed to separate the small particles which do not require crushing from the material which does (Pulkki 1980). In this way the small particle sizes, which would cause crusher head choking if wet, would by-pass the crusher head and be dropped directly onto the off-feed conveyor. Although no data is available pertaining to the effect of by-passing the small particles, it is felt that cost savings can be achieved, especially if the fine material is wet and gummy.

The crusher head type employed should be a single jaw type which crushes by compressive force only. The size of the jaw opening should be chosen so that particles as large as possible can be crushed without the weight of the crusher head being excessive. Generally, the weight of crusher heads increase considerably (from about 8 000 kg to 13 000 kg) with an increase in jaw opening size from 35...40 cm to 50...55 cm. Therefore, a jaw opening size of about 40 cm appears to be the optimal size since a large and expensive undercarriage would not be required. Going to a larger crusher head size would require a larger undercarriage and thus raise the hourly rate of the unit and reduce its mobility. However, further study is required to determine the optimal head size to use.

It is important to match an excavator to the system which has a feeding capacity which is slightly higher than the crushing capacity of the crusher. This is necessary since the cost of the excavator increases as its capacity increases. The above was apparent in method 4 where the excavator capacity far exceeded that of the crusher and 48.2 per cent of the excavator working time was spent waiting to feed the crusher.

Attention should also be focused on how to improve the work technique of the excavator at roadside crushing sites. For the methods where crushing occurred at roadside the productive crushing time lost due to the crusher waiting for material to crush, on the average, was 9.2 per cent. This loss of productive crushing time was more or less totally attributed to the excavator stripping and landscaping the borrow pits. Therefore, whenever possible, material to be crushed should be excavated from roadside banks (backslopes) and not from the sideslopes. In this way a wider road can be obtained at the crushing site at no extra cost, curves widened, hills in the road can be lowered, excavating production maximized, roadside borrow pit holes avoided and landscaping and stripping time minimized. In all situations during this study it was observed that when excavating from a face the crusher system's production capacity was maximized.

When excavating from a face (i.e. a roadside bank) is not possible, the material must not be excavated from directly beside the road. This is because the road structure would be weakened and considerable work required to repair the structural and aesthetic damage. The excavator should be positioned so there is a strip of ground, the width of the excavator, between the crusher and the borrow pit. The borrow pit should be elongated and run parallel to the road.

Any over-sized rocks can then be placed on the ground between the crusher and the borrow pit. When crushing is finished at the location, the rocks can be easily moved back into the hole and covered. The area beside the road should be levelled to produce a good meeting point or wood pile-down site. If the borrow pit is elongated it is easier for a small-sized tractor-digger to cover the rocks and shape the banks of the pit.

46. Other possible mobile crusher types

The Mertsa mobile moraine crusher is a self-propelled crushing unit where the crusher head, feed conveyor and off-feed conveyor are mounted on an old 20 t front-end loader chassis. In Finland, there are a large number of 20 t loaders of this type which were sold during the late 1960's and early 1970's, and which are presently being put out of active service.

Machines of this type are very applicable for use as chassis for crushers once they have been reconditioned. These chassis can presently be used to construct excellent mobile crushers since the work strain is not great. The construction of a new 20 t self-propelled chassis solely for crushing work may be too expensive to be feasible. It is unlikely that the costs involved would be recovered by the benefit that would be derived from self-propulsion, since the actual moving time is minimal: according to the time study, only 2.3 per cent of the total working time on the average.

Instead of used 20 t loader chassis, large forest tractors could be used. The crusher unit could be placed directly on the bunk or mounted onto the chassis as a special attachment instead of a bunk. In this way the field of forest tractor use could be broadened. In Finland, there are about 650 forest tractors with sufficient power and size for the above use. The hydraulic knuckle-boom loader could be used to removed over-sized rocks from the feed opening or it could even be used, when equipped with a special attachment, to feed the crusher head. The loader could also be used to lift the crusher head and other equipment off and/or on the forest tractor during repairs, maintenance or when switching from one type of work to another (i.e. from crushing to forwarding wood).

In addition to self-propelled units, another possible solution could be the use of a movable trailer chassis. The excavator or a truck could be used to move the crusher-trailer unit between borrow pits. However, to be applicable to forest road situations, the entire crusher-trailer unit must be of small size. An example of this type of solution is the Sorri crusher which was shown in Fig. 9 (p. 21).

To determine whether the self-propelled or movable trailer version is the best method to use will require more research. It could be possible that the two versions could both be used in the conditions in which they work best.

SUMMARY

The report outlines a study analysing the various work methods and feasibility of the Mertsa mobile moraine crusher in forest road pavement construction. Recommendations were made for work method and crusher improvements, as well as for new work techniques.

From the time study results it was apparent that when crushing at roadside, the borrow pit spacing should allow the use of a crushing method where the crushed material is dropped directly onto the road subgrade and a front-end loader type machine, equipped with grader blade, used to haul and spread the material. For system flexibility, the hauling and spreading capacity should be slightly higher than the crusher production capacity. A borrow pit spacing from 50 to 150 m, depending upon the work site conditions, was recommended.

It was found that by increasing the complexity of the work method (i.e. by using larger feeding equipment or more hauling vehicles), the cost of the crushed material was increased. By employing simple methods the mobile crusher system is very flexible and easy to adapt to varying work site conditions. It is also important to match an excavator to the system which has a feeding capacity which is slightly higher than the crusher capacity.

The maximum production rate (top size 55 to 66 mm) which can be expected from a mobile crusher, when crushing in a gravel pit, is approximately 55 m^3/h. When crushing at roadside the maximum production rate can be expected to be approximately 40 m^3/h. The minimum crushed material cost was 13.15 FIM/m^3 (method 3). The maximum crushed material cost was 26.36 FIM/m^3 (method 1-B). These costs are for the crushed material spread and graded on the road and are in 1979 FIM. The lowest material costs were obtained when crushing occurred in abandoned gravel pits. However, the hauling distance from the gravel pit should not be greater than 8 km, if crushing can be done at roadside.

Assuming that the assumptions made during this study are valid, and by employing the proper work methods, it can be safely said that the crushing method resulted in lower road construction costs, compared to conventional gravel hauling, when the hauling distance was over 7 km. Based on the results obtained, it can be said that by employing improved crusher work techniques, when crushing at or within the immediate vicinity of the road construction site, the cost of feeder road construction would be lower than when using the conventional methods, if the gravel hauling distance is over 1 km. However, this competitiveness is mainly due to the 45 per cent reduction in the quantity of material required for the road pavement.

To eliminate productive crushing time loss due to over-sized rocks, sloping steel beams, spaced not to allow a rock larger than the maximum particle size accepted by the crusher head, should be placed over the feed basin. A vibrating steel screen should also be employed to allow the small particle sized material to by-pass the crusher head. A crusher head with a maximum jaw opening size of approximately 40 cm appears to be the most suitable for small mobile crushers.

Whenever possible, material to be crushed at roadside should be excavated from roadside embankments (faces). When excavating from a face is not possible, the material should not be excavated from directly beside the road. The excavator should be positioned so there is a strip of ground, the width of the excavator, between the crusher and the borrow pit. The borrow pit should be elongated and run parallel to the road. Any over-sized rocks should be placed on the ground between the crusher and the borrow pit to allow for easy replacement of the rocks into the borrow pit. Once the rocks have been covered, the ground beside the road should be levelled to produce a good vehicle meeting point or

wood pile-down site.

Employing a reconditioned 20 t front-end loader chassis as the undercarriage for the crusher is a feasible solution today. The cost involved to construct a new chassis of this size solely for crushing work and the amount of time the self-propelling function is actually required, may make its construction unfeasible. Large forest tractors are another feasible solution for the self-propelling design. In addition to useful lifting work, the hydraulic knuckle-boom loader on the forest tractor could even be used to feed the crusher head if it was equipped with a special attachment. Finally, another feasible crusher design may be a movable trailer-crusher unit. Further research is required to determine which design alternative, self-propelling or movable trailer, is the most feasible. It may be possible to use both types in situations most favourable to their construction.

To obtain the maximum benefit from the crushed material it should be used on properly drained and compacted subgrades. Proper locating of the road is also important and compaction of the pavement layer should not be forgotten.

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SELOSTE

Liikkuva moreeninmurskain metsätien rakentamisessa

Liikkuvalla Mertsa-moreeninmurskaimella suoritettiin työntutkimus ja siihen liittyvä kustannusanalyysi eri työmenetelmien ominaisuuksien selvittämiseksi. Tarkoituksena oli etsiä parannuksia työmenetelmään ja murskaimeen sekä mahdollisesti laatia tutkimuksen tulosten perusteella uutta tekniikkaa ja menetelmää koskevia suosituksia.

Työntutkimuksen tulokset osoittavat, että suoritettaessa murskausta tienvierustalla moreeninottokuoppien välinen etäisyys tulisi järjestää sellaiseksi, että olisi mahdollista käyttää murskausmenetelmää, jossa murske pudotetaan suoraan tielle. Materiaali voidaan silloin ajaa ja levittää haluttuun kohtaan tasoituslevyllä varustetulla etukuormaajan tyyppisellä koneella. Jotta menetelmä olisi joustava, tulisi murskeen ajo- ja levityskapasiteetin olla hieman suurempi kuin murskaimen tuotoskapasiteetin. Työmaaolosuhteista riippuen suositeltava moreenninottokuoppien välinen etäisyys on 50—100 m.

Tutkimuksesta käy ilmi, että käyttämällä suurempaa syöttökalustoa tai useampia kuljetusajoneuvoja murskeen kustannukset nousevat. Jos käytetään yksinkertaisia menetelmiä, liikkuva murskainsysteemi on hyvin joustava ja helppo mukauttaa vaihteleviin työmaaolosuhteisiin. Menetelmää sovellettaessa olisi syytä käyttää sellaista kaivukonetta tai traktorikaivuria, jonka syöttökapasiteetti on hieman suurempi kuin murskaimen tuotos.

Liikkuvan murskaimen arvioitu maksimituotos (raekoko 55—66 mm) on keskimäärin 55 m^3/h murskattaessa sorakuopalla. Kun murskaus suoritetaan tienvierustalla, maksimituotoksen voidaan arvioida olevan 40 m^3/h.

Murskekustannukset (vuoden 1979 tasoa) olivat alhaisimmillaan 13.15 FIM/m^3 (menetelmä 3) ja ylimmillään 26.36 FIM/m^3 (menetelmä 1-B). Kustannukset kattavat myös murskeen levityksen ja tasoituksen tielle. Alhaisimmat materiaalikustannukset saavutettiin, kun murskaus suoritettiin vanhoilla sorakuopilla. Ajomatka sieltä ei kuitenkaan saisi olla pitempi kuin 8 km, jos murskaus on mahdollista suorittaa myös tienvierustalla.

Jos tutkimuksen aikana tehdyt olettamukset pitävät paikkansa ja jos käytetään oikeita työmenetelmiä, voidaan todeta, että murskausmenetelmää käyttämällä saatiin tavanomaisia soranajomenetelmiä alhaisemmat tienrakennuskustannukset silloin kun ajomatka on yli 7 km. Saatuihin tuloksiin viitaten voidaan lisäksi sanoa, että käyttämällä parannettua murskaustyötekniikkaa tienrakennustyömaalla tai sen välittömässä läheisyydessä murskattaessa, varsitien rakentamiskustannukset voidaan pitää alhaisempina kuin käytettäessä tavanomaisia soranajomenetelmiä, jos ajomatka on yli 1 km. Tämä johtuu kuitenkin lähinnä siitä, että tien päällystämiseen tarvitaan mursketta 45 % vähemmän kuin soraa.

Ylisuuret kivet tukkivat murskaimen kita-aukon ja aiheuttavat tehollisen murskausajan menetystä. Tämä voidaan estää asentamalla syöttökouruun viettävät teräspalkit, jotka eivät päästä liian suuria kiviä kita-aukkoon. Värähtelevä teräsverkko puolestaan päästää pienikokoisen materiaalin murskauspään ohi. Murskain, jossa kita-aukko on noin 40 cm, näyttää olevan sopivin pieniin liikkuviin murskaimiin.

Murskattaessa tien vierellä tulisi materiaali mahdollisuuksien mukaan kaivaa tienvieruspenkoista. Jos penkkaa ei ole, ei materiaalia pitäisi ottaa välittömästi tien reunasta. Kaivukone tai traktorikaivuri olisi sijoitettava niin, että koneen levyinen maakaistale jää murskaimen ja moreenikuopan väliin. Moreeninottokuoppa tulisi kaivaa pitkänomaiseksi ja tien suuntaiseksi. Kaikki ylisuuret kivet olisi laskettava maahan murskaimen ja moreeninottokuopan väliin, jotta kivien laskeminen takaisin kuoppaan kävisi helposti. Kun kivet on peitetty, tulee maa tasoittaa, koska siitä saadaan kohtaamispaikka ajoneuvoille tai puutavaran varastointialue.

Kunnostettu 20 t:n pyöräkuormaajan runko soveltuu käytettäväksi murskaimen alustakoneena. Uuden itseliikkuvan peruskoneen rakentaminen vaatii siitä saatavaan hyötyyn verrattuna melkoisia kustannuksia, joten sen suunnitteluun ei liene syytä ryhtyä. Suurta metsätraktoria voitaisiin myös käyttää peruskoneena. Metsäkoneen kuormaajaa voitaisiin käyttää nostotyön lisäksi murskaimen syöttämiseen, jos se varustettaisiin lisälaitteella. Käyttökelpoinen ratkaisu voisi edelleen olla perävaunun päälle rakennettu murskain. Vielä ei voida sanoa, kumpi, itseliikkuva vai vedettävä alusta, on parempi vaihtoehto. Mahdollista on, että kumpikin malli soveltuu käytettäväksi tietynlaisissa olosuhteissa.

Jotta murskeesta saataisiin suurin mahdollinen hyöty, sitä tulisi käyttää vain asianmukaisesti ojitetuilla ja tiivistetyillä tien rungoilla. Tien oikea sijoittaminen ja päällystekerroksen tiivistäminen on niinikään tärkeää.

PULKKI, R & AITOLAHTI, M. 1982. A mobile crusher for forest road construction. Seloste: Liikkuva moreeninmurskain metsätien rakentamisessa. Commun. Inst. For. Fenn. 107:1—30.

Appendix A — liite A

Technical data for the Mertsa mobile moraine crusher

The majority of this data was presented by Ylä-Hemmilä (1978). The Mertsa crusher is a prototype built mainly from reconditioned components.

General information:

length — 10 000 mm
width — 3 200 mm
height — 3 700 mm
GVW — approximately 25 000 kg
chassis type — a reconditioned 20 000 kg Michigan wheeled front-end loader chassis with a frame extension of 1 m
engine type — 11 l, 6 cyl., 4 cycle, turbo-charged Scania diesel engine
— maximum power 204 kW SAE/33 r/s
— maximum torque 1 000 Nm SAE/23 r/s

Crusher head information[1]:

type — Arbrå R 6040-96 jaw crusher
feed opening — 600 mm×400 mm
maximum feed size — 350 mm ∅
setting range — 25...100 mm
weight — 9 000 kg
capacity — 30...65 m³/h (according to manufacturer)

Power transfer to the crusher head:

The crusher head was driven by two hydraulic motors with a combined power of approximately 40 kW. The output of the hydraulic pump under normal working conditions was 4.8 dm³/s with a system pressure of 10 500 kPa. The crusher head fly-wheel spun at 7.6 r/s and, if required, the production could be increased by increasing the system pressure.

Feed and off-feed conveyors:

A conveyor driven by a 6 kW hydraulic motor was used to feed the crusher head. The conveyor speed could be varied from 0.0 to 2.0 m/s. The off-feed conveyor was also powered by a 6 kW hydraulic motor but the speed of the conveyor was fixed.

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[1] When the study was carried out the crusher was equipped with the head mentioned above. The head has since been replaced and the new crusher head data is as follows. A grate has also been places before the crusher head to by-pass the fine material past the crusher head.

type — Lokomo C-63 jaw crusher
feed opening — 630 mm × 440 mm
setting range — 40...150 mm
driving power required — 45...55 kW
specified fly-wheel speed — 6.7 r/s
weight — 5 500 kg
capacity — 21...104 m³/h (according to manufacturer)

Appendix B — liite B

Tutkitut työmenetelmät

1-A. Moreeni murskattiin suoraan kuljetusajoneuvoihin pienillä tienvieruskuopilla. Brøyt x-20 kaivukonetta käytettiin syöttämään murskainta. Kuljetusajoneuvoina olivat Volvo N-86 kuorma-auto ja Fiat 1000 DT Super traktori. McCormick International 434 traktoria varustettuna kuormaimella käytettiin ajoittain korvaamaan Volvoa.

1-B. Moreeni murskattiin suoraan kuljetusajoneuvoihin pieniltä tienvieruskuopilta. RH-6 kaivukonetta käytettiin murskaimen syöttöön. Kuljetuskoneet olivat Sisu, Jyry ja Sisu Regular. Keskiraskasta tasoittajaa (keskim. 12 tonnia) käytettiin murskatun materiaalin tielle levitykseen.

1-C. Moreeni murskattiin suoraan kuljetusajoneuvoihin pieniltä tienvieruskuopilta. Valtra UM-353-CM traktorikaivuria käytettiin syöttämään murskainta sekä Fiat 1000 DT Super traktoria kuljettamaan ja levittamään mursketta.

2-A. Murske pudotettiin suoraan tien pohjalle kasoihin ja moreeninottopaikat olivat 150—500 m:n välein. Valtra UM-353-CM traktorikaivuria käytettiin murskaimen syöttöön ja Fiat 1000 DT Super traktoria materiaalin levitykseen etukuormaajaa ja traktorin alapuolelle asennettua tasoituslevyä käyttäen. Levitys tapahtui samanaikaisesti murskaustoiminnan kanssa.

2-B. Sama kuin 2-A paitsi että moreeninottokuopat olivat 5—10 m:n välein.

2-C. Sama kuin 2-A, mutta moreeninottokuopat 10 m:n välein ja levitys tapahtui yhdellä kertaa murskauksen jälkeen.

3- Murske pudotettiin suoraan kuljetusajoneuvoihin ja murskaus tapahtui isolla sorakuopalla, missä soramoreeni oli kuivaa ja karkeaa. RH-6 kaivukonetta käytettiin murskaimen syöttöön ja kaksi Sisu kuorma-autoa ajoivat mursketta. Tasoittajaa käytettiin materiaalin levitykseen tielle.

4- Murske pudotettiin suoraan varastoon ja murskaus tapahtui isolla sorakuopalla, missä soramoreeni oli kuivaa ja karkeaa. Murske levitettiin myöhempänä ajankohtana Fiat 1000 DT Super traktorilla ja irtolavalla. Fiat lastasi irtolavan käyttäen etukuormaajaa, joka oli traktorin varusteena. Sitten traktori kiinnitettiin koukulla irtolavaan kuormauksen jälkeen, materiaali ajettiin levityspaikalle ja levitettiin. Brøyt x-20 kaivukonetta käytettiin murskaimen syöttöön.

ODC 383.7
ISBN 951-40-0590-2
ISSN 0358-9609

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ODC 383.7
ISBN 951-40-0590-2
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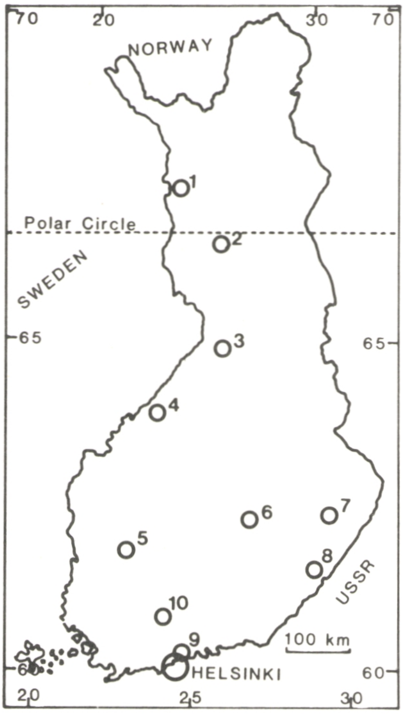

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FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. <0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

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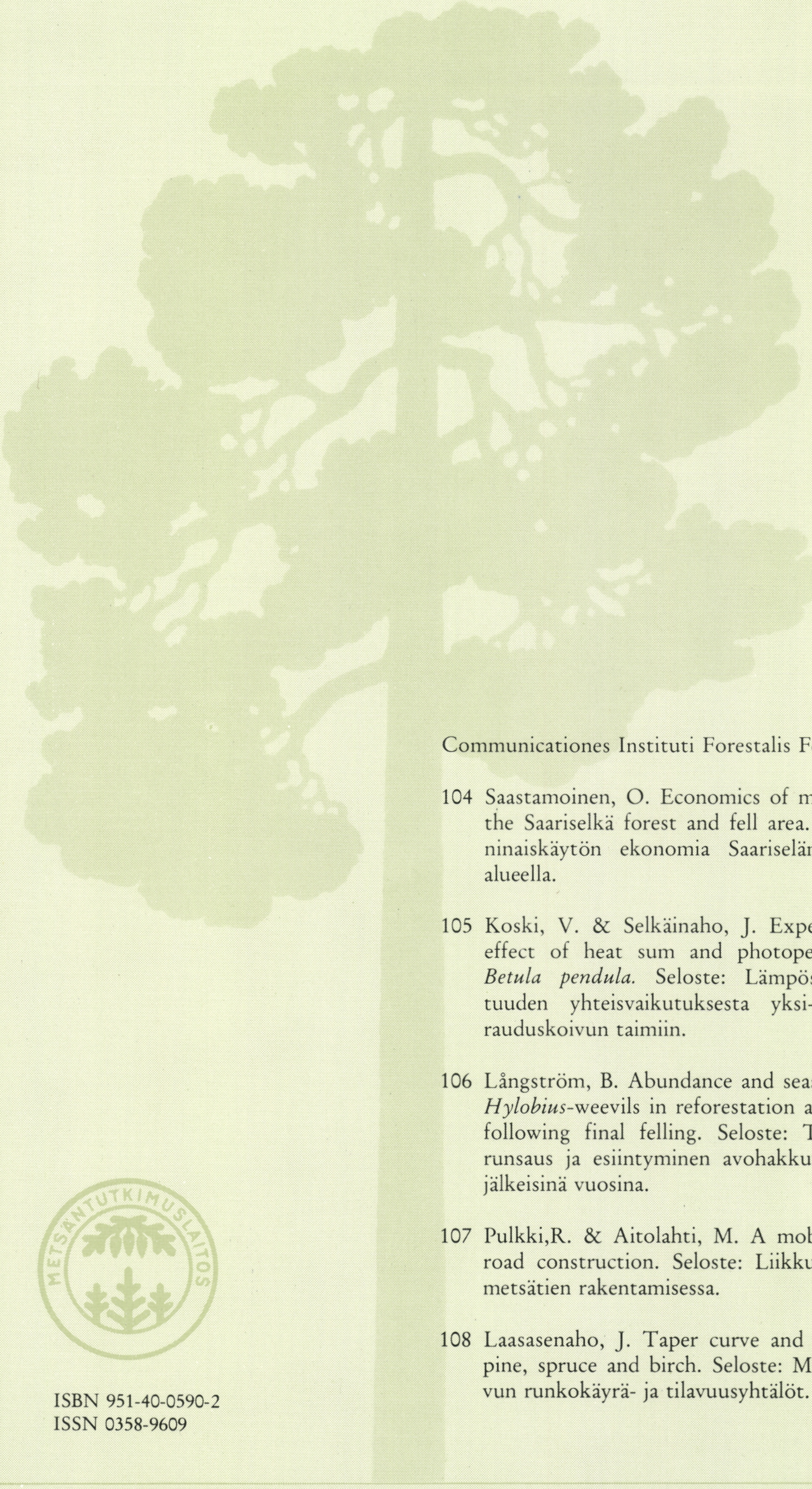

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