The Monte Carlo method of farm planning

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IN 1964 a mimeographed paper(1) about "The usefulness of the Monte Carlo-method for studies of economic planning models", was presented at a seminar in Upsala, Sweden. It dealt with the preliminary results of the application to farm planning problems of a Monte Carlo-method originally developed for the dimensioning of electronic magnets(29). Four planning problems were analysed and comparisons made with the result from analyses with linear programming (LP) and a method of programme planning.

It was stated that the Monte Carlo-method seemed to have advantages compared with LP in the following respects: many solutions were obtained, many objective functions could be included and interaction between them could be studied, non-linear relations and integer formulations could be included, minimum levels for activities could be specified to eliminate ridiculously small levels, interaction between activities due to, for example, rotational yield effects could be included and the maximum number of activities could be fixed. Some of these advantages were only deduced from the general structure of the model and not studied in the practical examples. Anyhow the method looked promising, in spite of its drawbacks, which were also discussed in the paper.

The Swedish studies have continued since 1965. They have mainly been concentrated on testing the method on different types of problems(20), on making the seeking-process more effective(3, 18, 20), and lately on the development of the method to make it suitable for investment planning, and in connection herewith, multi-objective problems(23). Bertil Hovmark, who from 1966 has taken over much of the work, is also conducting a large study where the Monte Carlo-method is used by the Royal Agricultural Board to analyse the profitability and risks of different "synthetic" farms.

The Swedish method has also been used in Danish studies. In(5,6) a comparison with LP was made. In(25) the latest Monte Carlo-programme has been compared with LP for handling integer problems and problems containing economies and diseconomies of size. In a Norwegian study(24) the Swedish Monte Carlo-method is compared with LP. Inspired by the Scandinavian work two studies on the Monte Carlo-method were published in the UK in 1967. One of them(9) presented a Monte Carlo-method ("Top Twenty" Farm Planning Method) which is almost identical with the Swedish method in the development stage described in(3, 6). The Top Twenty-method has been tested mainly on traditional LP-farm planning problems(11, 12, 21). The other study(7) was inspired by a personal visit by Steve Thompson to Sweden in 1966. Although the general idea is similar to the Swedish method, it differs in some respects. This method has been tested on feed problems(8) and on investment problems in connection with traditional planning problems(15-17, 19).

I am indebted to Mr. Bertil Hovmark, Agricultural Colleges of Sweden, Upsala, for his valuable suggestions.

The Monte Carlo-method

It would take too large a part of this article to give a complete description of the Monte Carlo-method. For such descriptions the reader is directed to(7, 11, 18). Instead some general features will be presented in conjunction with a graphical presentation of a traditional product mix problem (fig. 1). In fig. 1 the LP-solution is marked, as are the possible Monte Carlo-solutions. These Monte Carlo-solutions are the population from which a sample is drawn by help of the seeking-process. The solution constituting the population can be defined as all (integer) solutions located within the restrictions and activity intervals allowed, and for which no activity level can be increased one unit unless some other activity is decreased or restrictions or activity intervals are exceeded.

The solutions calculated are the primary output from the computer. For these solutions the values of different objective functions, the activity levels, and the amount of unused resources are given. The simplest way of presenting the solutions calculated would be as in table 1. In the early Swedish studies, as well as in the "Top Twenty-method", the result is just presented in the form of a list including a given number of the best solutions. In later Scandinavian studies all the solutions are used to calculate "statistics", of different kinds. Among other things the statistics show, for different levels of the objective function(s), (a) number of solutions, in total and those including special activities, (b) minimum and maximum levels registered for activities and (c) unused resources. The statistics, which are intended to give a better description of the planning problem, will be discussed further below.

In the latest Swedish programme Hovmark has built in what he calls "resource activities". The seeking-process then starts by randomly choosing new resources, which are added to the fixed resources of the farm (see fig. 1). It might be land, new buildings, hired men, grassland for fodder production and so on. Then the "traditional" production activities are combined within the fixed and the randomly chosen resources. Finally unused randomly chosen resource activities are eliminated. Such resource activities have been used by Hovmark in(23) and in one of the Danish studies(25). In the programme developed by Thompson it is also possible to handle such problems(7). Comparative studies between the usefulness of the different methods have not been made.

Applications of the Monte Carlo-method on "pure" LP-problems

Most of the planning problems hitherto analysed with the Monte Carlo-method are such which can also be analysed with LP. It was natural in the beginning of the Monte Carlo-studies to choose LP-problems as test problems, because the main question at that time was "how close to the optimal solution could one come with the Monte Carlo-method" (see part 5). But comparisons of the value of the information which the decision maker got from a LP-planning with that from the Monte Carlo-method also turned out to be of great interest. This will be discussed below.

Experiences from using the HUV-method—a programme planning method used in Sweden—had earlier pointed to the value of presenting several solutions to the decision maker(3 p. 62). Studies with various other techniques to generate many "sub-optimal plans"(30) have the same motivation. This motivation contains among other things the following sub-aspects: (a) uncertainty about the farmers' goals; (b) difficulties of getting farmers (decision makers) to combine the various objective functions into a single function prior to receiving some information about possible plans(27 p. 180); (c) the well-known, but in practice not always recognised, fact, that optimal solutions obtained from a model are optimal with respect to reality only if there exists a complete isomorphism between model and reality; (d) in many farm planning problems the solution space is relatively "flat" in the region of the optimum(32).

In the first Monte Carlo studies just the different solutions were printed out. But when the number of solutions generated increased, different methods of systematising the information were developed. This has been mentioned already under point 2. At first the activities where analysed and grouped into PLUS-, MINUS- and INDIFFERENT-activities, where a PLUS-activity must enter a solution in order to yield values of the objective function above a given value, while MINUS-activities cannot enter such solutions, and INDIFFERENT both can and cannot(3). Other information which was generated concerned possible activity levels and resource use at different levels of the objective functions. Such information was also presented in diagrams(3). The studies of resource use at different levels of the objective function have given rise to comparisons with the information about "shadow prices" in LP(10). In other studies efficiency-lines have been plotted showing e.g. the "trade off" between gross margin and risk(10), capital need and income(14, 15), or some other objectives. Today the Swedish programme also analyses the solutions with regard to the best solution(s) containing a given activity, and the best solution(s) with a given number of activities.

The value of the information discussed above to farmers (decision makers) has not yet been tested, but I have the experience that such calculations are easy to explain to people and increase the knowledge of the planning problem, compared with what is normally received with traditional LP or programme planning methods.

Model building possibilities with the Monte Carlo-method

Traditionally some problems concerning the possibility of describing the planning problem in an adequate way have interested economists and mathematicians. I here think of non-linear relations, integer formulations and similar problems. As was clear already in the early publications on the Monte Carlo-method, some of these problems could easily be handled with the Monte Carlo-method. They will be discussed below. It should be noticed that the author has no experience of using integer, non-linear and similar programming methods. Therefore, opinions about their usefulness had to be taken from the literature.

Dealing with non-linearity

The general form of the resource use coefficient for individual activities is "qu + ax", where "q" is a fixed portion and "a" a linear coefficient. This formulation is used in the Monte Carlo-method and has been sufficient for describing labour consumption as a function of the activity level. Other forms are also possible(1). It should be noticed that in the present programme, it is also possible to use q-terms common for many activities, of which each has its individual a-terms.

The objective functions can have an arbitrary form, because their values are calculated after the solution is chosen. Christensen published in 1970 a comprehensive study(25) in which he compared LP and the Monte Carlo-method on practical planning problems including economies and dis-economies of size as well as integer formulations. He concludes that the problems analysed could be solved adequately with both methods. With the LP-approach it was, however, necessary for many problems to take out the problems from the computer repeatedly for adjustment. Personally, I have the feeling that the description of the different LP-methods is more difficult to understand and to handle compared with the more straightforward Monte Carlo-formulations. In practical management this is of course important, if it is true.

Reisch(31 p. 10) concludes about non-linear objective functions that the applications in agriculture "haven't been more than academic experiments. There is little hope for practical usefulness of these 'more powerful models' in the near future, since they require large computer capacities".

Dealing with integer variables

Integer formulation has hitherto been most used in Monte Carlo-studies, although continuous variables can also be used. Examples including many 0-1-activities are presented in(20). It is also described there how "either-or-or . . . or" formulations can be included by a proper use of the q-terms discussed under the section dealing with non-linearity. Such formulations are of special value when glasshouse enterprises are planned. In such cases "whole houses" of different sizes are the base activity units.

According to Reisch(op. cit. p. 10) different modifications of the Simplex method can be used for analysing problems including integer formulation.

Dealing with risk and uncertainty

When many plans are presented to a farmer he probably considers their "risks" subjectively when he makes his choice(3 p. 62). This is the simplest way to handle the uncertainty problem(26). The possibility of building arbitrary objective functions has also been used to calculate the risk as the standard deviation of the gross margin and to estimate "efficiency lines"(10, 18, 20). The risk calculation can also be supplemented with liquidity calculations. Hovmark concludes in a study(23) that "the introduction of liquidity measures to the criteria for ranking the solutions has a great importance for which of the action possibilities will be the best".

Quadratic programming as well as other methods to handle risk and uncertainty in management solutions are discussed by Reisch(op. cit. pp. 11-12). He concludes that they need "much preparatory and computational work and are very demanding with respect to their data need". The need of data is of course the same for the Monte Carlo-method, but there are no special computational difficulties involved.

Some other problem formulations

Some other interesting possibilities with the Monte Carlo-method will be mentioned briefly. In some studies(10, 18, 20) the possibility of including interaction between activities due to rotational yield effects has been used. In most Monte Carlo-studies the use of minimum activity levels has been used, thus excluding levels without practical interest. It should be noticed that such minimum levels do not force the activity into the solution as in LP, because zero is always a possible level. Also the possibility of regulating the maximum number of activities in a solution has been used for "specialisation analyses" where the effect on income and risk of a decreased number of activities has been studied(20). Finally it should be mentioned that the "q-terms" can be used in so called "combination restrictions". In(10) they are used to regulate the maximum number of animal activities that can share the same building. Formulations which e.g. have the effect that either activity A or a combination of activities B and C can be included in a plan are also possible(20). With the Swedish programme used in studies published hitherto there were some difficulties with the problem formulation if one wanted to put a minimum level for a sum of activity levels and also when the amount of internal production must be equal to internal comsumption, i.e. there exist no selling and buying possibilities. The developments of the method undertaken by Hovmark seem to eliminate these problems, at least partly. Thompson's Monte Carlo-programme(7) can handle such problems.

How effective is the seeking-process?

It is obvious that the more solutions that are generated, the better will be the information obtained. In(20) the marginal change in information from a successively increased number of solutions was studied. The value of increased information can then be weighed against the cost of this information in order to find some optimal number of solutions. Some results from the studies will now be presented. As already mentioned the main interest of the earlier studies was concentrated on the question "How close to the optimal solution can you come with the Monte Carlo-method?" In most of these studies, as well as in later ones, it was concluded that after 1,000-2,000 solutions, sometimes divided into two steps, the best solutions were almost identical with the LP-optimum. When remarkable differences occurred it was mostly due to the fact that the Monte Carlo-solution was an integer solution.

Information about possible activity levels at different levels of the objective function is received from the statistics, as has been mentioned. In(20) comparisons are made between activity levels registered in short and long series. It was found in the examples analysed, that the activity levels registered in series of 500-1,000 solutions were mostly the same or almost the same as in longer series, and that they therefore probably gave a good estimate of the "true" levels. Calculations of how "true" the RA-values are (RA-values are the the basis for grouping the activities into PLUS-, MINUS-, and INDIFFERENT-ACTIVITIES and are also used in the multi-step seeking process) have also been made in(20). It is concluded that the risk of characterising activities as PLUS- or MINUS-activities, when they really are INDIFFERENT, is rather limited in the problems analysed. Both the RA-values and the information about possible activity levels at different levels of the objective function will be studied on the basis of probability-theoretical models.

Also efficiency lines estimated from a small number of solutions were compared with corresponding estimates from a larger number. Such comparisons were also made for the "lines" showing the minimum resource use at different levels of the objective function. In both cases 1000-2000 solutions were enough for the problems analysed to give sufficient information.

In this connection some words should be said about the costs of Monte Carlo-planning. In early studies these were calculated and found reasonable(1, 5). Today's programme is built out on the "statistics side" for research purposes. This, of course, means a higher cost per solution calculated. It is therefore difficult to give the exact cost of the use of Monte Carlo in practical planning. But there is no reason to assume that the cost would limit its use. It should also be noted that not only the computer is of relevance. All other work included in the planning process must be included.

Concerning the size of the analysed matrices it should be noted that LP-formulations normally need bigger matrices than Monte Carlo-formulations. The reason for this is the use of many objective functions, "functions" instead of simple coefficients, minimum and maximum limits for activity levels and so on. For example, Hovmark recently analysed a problem which contained only 14 independent activities, but which nevertheless included 620 parameters with values $\neq 0$. These model building possibilities imply that all present farm planning problems have been capable of analysis with the Monte Carlo-method.

The usefulness of the Monte Carlo-method for practical farm planning

It is almost trivial to state that different OR-methods (operation research-methods) might be more or less useful for different purposes(28). Therefore it is impossible to say that one method is better than the other. Such statements are only possible in relation to special problems. Nevertheless the following general remarks about the usefulness of the Monte Carlo-method for practical farm planning can be made.

First, it is obvious that in practical farm planning there is a growing interest in getting more than one solution to present to the farmer. The Monte Carlo-method can in such cases be a useful complement to linear programming. It will be interesting to compare different techniques to generate "sub-optimal" solutions(30) with the Monte Carlo-technique. Also the informative value of the statistics calculated need to be studied.

Secondly the Monte Carlo-method might also be an interesting method to use when the different model building possibilities are necessary for an adequate model. Especially, I think that the Monte Carlo-method might be an interesting alternative when many such problem formulations are to be considered simultaneously. This can easily be handled with the Monte Carlo-method, but might be difficult with other methods.

Thirdly it seems today as if the information received from the Monte Carlo-method is sufficiently "true" for practical planning problems, and that it can be produced at a reasonable cost. Also, the matrices which normally occur in practical farm management problems have all been of a size possible to handle with today's programme and computers.

List of references

A. Bibliography on the Monte Carlo-method for farm planning.

1. Lindgren, I. & Carlsson, M., 1965. **Monte Carlo-Metodens Andvändbarhet för Studier Av Ekonomiska Planeringsmodeller** (mimeo).
Avd. för trädgardsodl. driftsek., Lantbrukshögskolan, Alnarp, Sweden. 25 pp.

2. Carlsson, M., 1965. **Tabeller Och Diagram Over Monte Carlo-Metodens Andvändbarhet för Studier Av Ekonomiska Planeringsmodeller** (mimeo).
Avd. för trädgardsodl. driftsek., Lantbrukshögskolan, Alnarp, Sweden. 27 pp.

3. Lindgren, I. & Carlsson, M., 1966. Företagsekonomisk planering med Monte Carlo-Metod. **Erhversokonomisk Tidskrift** Nr 2, pp. 61-89.

4. Carlsson, M., 1966. Monte Carlo-Metoden för företagsekonomisk planering.
NJF:s Studieseminarium för Yngre Lantbruksekonomer. (Ultuna, 1966). Föredragssamling. Komplement till föredragssamling vid studieseminariet i Helsingfors, 1965. pp. 43-53.

5. Stryg, P. E., 1966. Monte Carlo-Metodens anvendelse i landbrugets driftsplanlaegning sammanlignet med lineaer programmering og bidragsmetoden.
Tidskrift för Landokonomi, pp. 427-52.

6. Stryg, P. E., 1967. Application of the Monte Carlo-Method and linear programming in farm planning.
Den Kgl. Veterinaer—Og Landbohojskolens Arsskrift. pp. 195-217.

7. Thompson, S. C., 1967. **An Approach to Monte Carlo Programming:** Dept. of Agriculture. Farm Management Section. University of Reading. Study No. 3. 42 pp.

8. Dent, I. B. & Thompson, 1967. The application of Monte Carlo-techniques to feed problems. **The Farm Economist** 11: 6, pp. 230-48.

9. Donaldson, G. F. & Webster, J. P. G., 1967. A simulation approach to the selection and combination of farm enterprises. **The Farm Economist** 11: 6, pp. 219-29.

10. Carlsson, M., Hovmark, B. & Lindgren, I., 1968. **Studies of Farm Planning Problems by a Monte Carlo-Method** (mimeo). Paper presented in May 1968 at the Symposium on Models and Simulation of Economic and Administrative Systems, Gothenburg. Printed 1970 in Gothenburg School of Economics and Business Administration Publications. 1970. 4. pp. 89-115.

11. Donaldson, G. F. & Webster, J. P. G., 1968. **An Operation Procedure for Simulation Farm Planning—Monte Carlo-Method.** Wye College Dept. of Agricultural Economics, 30 pp.

12. Webster, P., 1968. Simulation Farm Planning—Monte Carlo-Method. **The Journal of the Farm Management Association** 1: 4, pp. 1-9.

13. Carlsson, M., 1969. Farm planning with a Monte Carlo-method. **Acta Horticulture** 13, pp. 113-121.

14. Dent, J. P., 1969. "Monte Carlo simulation—a new approach to farm planning". **N.A.A.S. Quarterly Review** No. 83, pp. 115-122.

15. Thompson, S. C. and Page-Wood, A., 1969. "Planning investment on a dairy farm". **Farm Management** 1, No. 6 pp. 22-30.

16. Thompson, S. C., 1969. "Monte Carlo for a weaner unit". **Farm & Country,** Sept. No. pp. 64-67.

17. Thompson, S. C., 1969. "Finding the best investment". **Pig Farming** 17, No. 11 pp. 42-45.

18. Carlsson, M., Hovmark, B. & Lindgren, I., 1969. "A Monte Carlo-Method for the study of farm planning problems". **Review of Marketing and Agricultural Economics (Sydney)** 37 pp. 79-102.

19. Dent, J. B. and Byrne, P. F., 1969. "Investment planning by Monte Carlo-simulation". **Review of Marketing and Agricultural Economics (Sydney)** 37 pp. 104-120.

20. Carlsson, M., 1969. **"Beskrivning Av Nagra Experiment Med En Monte Carlo-Metod för Företagsekonomisk Planering"** (mimeo). Lantbrukshögskolan, Uppsala 63 pp.

21. Seuster, H., 1969. Simulation landwirtschaftlicher Betribs-organisationen. **Agrarwirtschaft** 18: 8, pp. 263-272.

22. Nix, J. S., 1969. Annotated bibliography on farm planning and programming techniques. **The Journal of Farm Management Association,** Vol. 1, No. 7, pp. 47-52.

23. Hovmark, B., 1970. **Liquidity Aspects of the Risk Problem in Farm Planning: A Multi-Objective Monte Carlo-Approach.** (Unpublished). Agricultural College of Sweden, Uppsala. 12 pp. (mimeo).

24. Repstad, K., 1969. **Monte Carlo-Metoden Nyttet Till Driftsokonomisk Planleggning I Landbruket.** Norges landbruksokonomiske institutt, Oslo. 40 pp.

25. Christensen, J., 1970. **Anvendelse Af Linear Programmering Og Monte Carlo-Metoden Ved Landbrugets Driftsplanlaegning. Lösning Af Planlaegningsopgaver Med Skalavirkning Og Delelighedsproblemer** (mimeo). Landbrugsministeriets driftsokonomiudvalg, Arhus. 192 pp.

B. Other literature

26. Carlsson, M., 1970. **Operation Research Methods in Planning and Management of Input-Intensive Crops Under Conditions of Uncertainty.** To be published in proceedings from: ISHS XVIIIth International horticultural congress, Tel Aviv, 1970. 5 pp.

27. Churchman, C. W., 1961. **Introduction to Operations Research.** New York, 645 pp.

28. Eisgruber, L. M. & White T. C., 1970. **The Mathematics of the Economy of the Individual Farm Business.** To be published in proceedings from: XIVth International conference of agricultural economists, Minsk 1970. 15 pp.

29. Lindgren, I. Optimum design of a Sixpole focusing atomic-beam magnetic-resonance apparatus. To be published in: **Nuclear Instruments and Methods.**

30. Powell, R. A. & Hardaker, I. B., 1969. Suboptimal programming methods for practical farm planning. **Review of Marketing and Agricultural Economics.** Vol. 37 pp. 121-129.

31. Reisch, E. M., 1970. **Recent Advances in Farm Planning in W. Europe and North America.** To be published in proceedings from: XIVth International conference of agricultural economists, Minsk 1970. 27 pp.

32. Renborg, U., 1962. **Studies on the Planning Environment of the Agricultural Firm.** Uppsala. 257 pp.

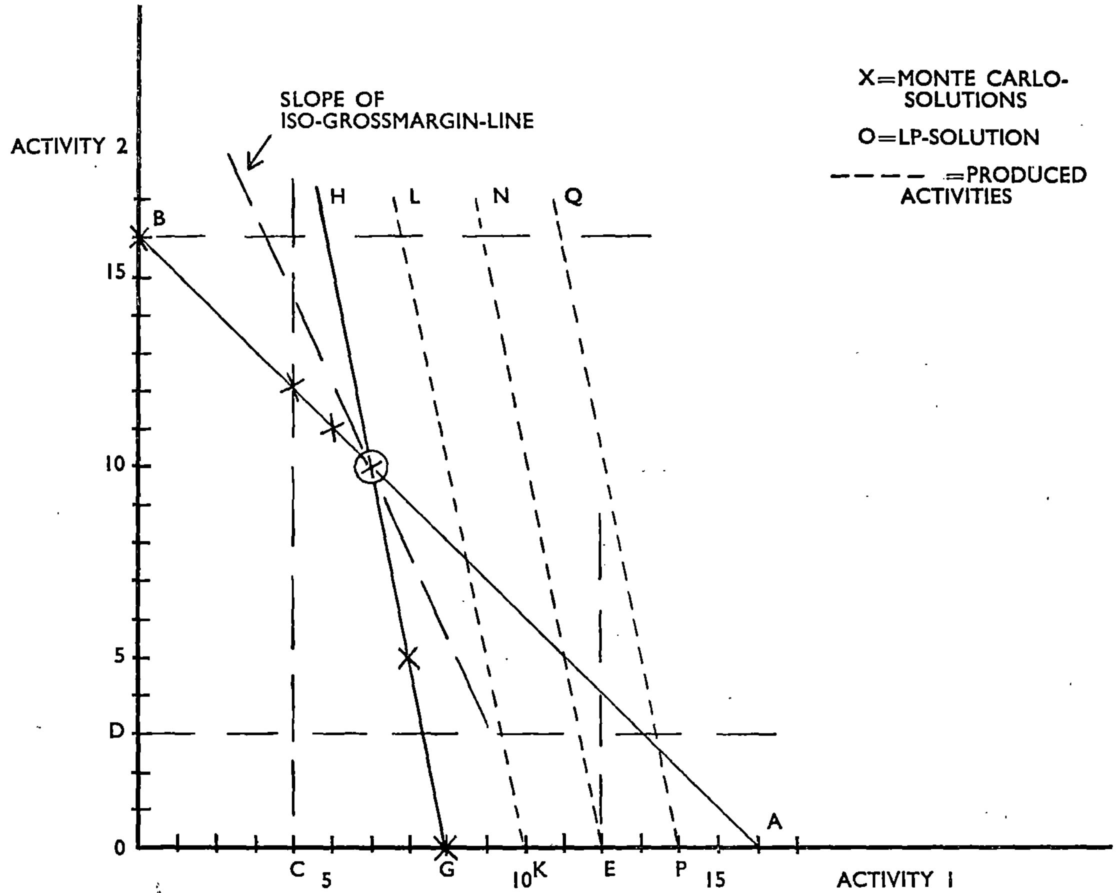

Fig. 1. The problem is to combine activity 1 and activity 2, within given resources (AB; GH) and activity interval allowed (O, CE; DB). If the slope of the iso-grossmargin-line is that shown in the figure, (6, 10) is the LP-solution. Possible Monte Carlo-solutions are (8, 0; 7, 5; 6, 10; 5, 11; 4; 12 and 0, 15), provided that step II in the seeking process is used to put the solutions on the "sphere". Using **resource activities,** the resource frame can be chosen randomly. GH is the given amount of one resource. This resource can be increased in integer steps to KL, EN, PQ respectively. This of course changes the feasible area and the possible solutions.

Table I

THE SIMPLEST WAY OF PRESENTING THE MONTE CARLO OUTPUT

Solution No.	*Values of objective functions No.*			*Levels of activity No.*				*Unused quantity of resource No.*		
	1	2	.	1	2	.	.	1	2	.
1	x	x	x	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x	x	x	x
3	x	x	x	x	x	x	x	x	x	x
.										
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S	x	x	x	x	x	x	x	x	x	x